A GUIDE TO QUALITY ASSURANCE
INDICATORS FOR THE DEFENSE
ELECTRONICS INDUSTRY

THESIS

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FOR THE DEFENSE ELECTRONICS INDUSTRY

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Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Systems Management

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September 1989

Acknowledgements

In researching the use of quality assurance indicators I have received a great deal of help from others. I am indebted to my thesis advisor, Lt Col Dick Moore, for his encouragement and assistance in the development and refinement of this study. I also wish to thank Mr. Fred Sulish (ITT), Mr. Fred Belcastro (TI), Mr. Bill Thomas (ESD), and Mr. Bob Craven (ASD) for providing the indicators and observations discussed in this study. Finally, I wish to thank my wife Carrie for her understanding and support during the trying times I spent paying more attention to my thesis than to the rest of the world.

Ron Goertz

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Abstract

The purpose of this study was to provide the inexperienced quality assurance specialist (QAS) with a guide to quality assurance indicators for use when working with contractors in the defense electronics industry. The quality indicators used by two defense industry contractors (ITT and Texas Instruments) with excellent quality programs were studied, as were the indicators used by two of the AFSC product divisions (ESD and ASD) that interface with the defense electronics industry.

This research focused on the elements of a MIL-Q-9858A quality program required for the complex systems produced by the contractors studied. Quality indicators and observations about quality programs were discussed, presenting the uses, merits, and shortfalls of the elements a QAS might find in an "ideal" quality program.

A GUIDE TO QUALITY ASSURANCE INDICATORS FOR THE DEFENSE ELECTRONICS INDUSTRY

I. Introduction

General Issue

The defense electronics industry constantly strives to provide the latest technology to the government in response to increasingly complex defense requirements. This has resulted in a dynamic industry, one which modifies its methods and resources as needed, based on ever-changing technology. This change is notable when comparing the technology required for the B-2 with the technology in even the most recently upgraded B-52. The electronic warfare threat and the requirements to counter that threat advance with each new generation of technology.

Many of the specifications and standards which govern the development of these high-tech systems, however, have not kept pace with the changing technology. The most recent revision of several specifications reveals that they are older than many of the individuals who rely on them daily. A newly assigned officer, who has witnessed the Apollo moon landing as well as the advent of the space shuttle, has seen dramatic changes in technology. In spite of this dynamic environment, the specifications he relies on to insure the design, production, and quality of the United States' next generation fighter remain unchanged.

The potential danger of aging publications is compounded by the Air Force's attempt to develop well-rounded officers. The goal is officers who are able to handle the varied environments of potential assignments. One technique used to broaden skills is the transfer of officers to a new position every one to four years. Although the long-term result of broadly knowledgeable officers is achieved, a short-term result is also realized: officers who are continually learning new systems, officers trying to do their best in an unfamiliar position. These officers need guidance on what to do and how to do it. Guidance, although readily available in the many regulations, standards, specifications, and handbooks published by the Air Force, is often obscured by the sheer magnitude of information available. The volume of the information alone often stands as a barrier to learning.

As noted above, many of these publications have been used as guidance for years, often for more than two decades. The primary publication guiding Quality Assurance Specialists (QASs), MIL-Q-9858A, "Quality Program Requirements," was revised most recently in December 1963. MIL-Q-9858A is intended for use in contracts involving complex end-items (such as missiles and aircraft) and their major components (including electronic systems and navigation systems). MIL-Q-9858A requires ". . . the establishment of a quality program by the contractor to assure compliance with the requirements of the contract," (4:3) and requires the contractor to use the program he has developed. The quality program developed not only must ensure the quality of the end product, but must also ". . . assure adequate controls throughout all areas of contract performance; e.g., development, manufacturing, and shipping" (4:3).

The associated "interpreting" handbook used in conjunction with MIL-Q-9858A is Handbook H50, "Evaluation of a Contractor's Quality Program," which was most recently revised in April 1965. Handbook H50 is intended for use by both the government and industry to clarify the intent and applicability of the specification. Each subsection of the specification is quoted, followed by a Review of the Requirement (general discussion on the intent of the subsection), Applications (examples of how the requirement has been applied in the past), and Criteria for Evaluation (criteria in the form of questions which should be asked by the reader in evaluating a section of the program).

The information contained within these publications is intended as general guidance only. The dates of last revision, however, suggest that the latest technologies and quality philosophies may not be represented.

The issue of outdated guidance for Quality Assurance specialists considers only one dimension; another facet of the problem is that Air Force contractors are required to comply with these guides. The result is Air Force officers evaluating state-of-the-art defense contractors, both of whom are guided by material most recently revised over 25 years ago.

If the defense industry were being well-managed under such guidance, no further discussion of this situation would be warranted. One does not have to look far, however, to note this is not the case. A recent article in the Air Force Times notes ". . . about 92 percent of parts sampled at a major Air Force supply center are of lower quality than was paid for . . ." (9:35). Further, a House Republican Research Committee report states that

> . . . quality experts estimate that the total cost of poor quality, or the cost of not doing the right things right the first time, is 20% of gross sales for manufacturing companies . . . . (16:2)

A third example of poor defense industry management is seen in a General Accounting Office report on B1B parts problems. The report cites low reliability, false test failures, and delinquent deliveries or missing delivery schedules as impediments to operating the B1-B (26:4-5). The emphasis of the examples is clear: either the Air Force, the defense contractors, or both are being inadequately guided in their efforts to provide quality products to the government.

Specific Problem

Quality Assurance Specialists (QASs) are currently being guided by a 25-year-old specification. While experienced QASs have perhaps developed a personal toolbox of guides or indicators that alert them to problems with a contractor's quality program, QASs newly assigned to quality assurance do not have this luxury. They must consult the available publications for guidance. As these publications are by design very general in nature, little current, specific guidance is available for measuring the status of a contractor's quality program. This thesis will address this problem by presenting a guide of specific indicators that can be used in evaluating defense electronics industry contractors.

Research Objectives

This study will summarize quality assurance indicators used by two defense electronics contractors (ITT and Texas Instruments) and two Air Force Systems Command product divisions (Aeronautical Systems Division and Electronics System Division) into a guide of quality indicators usable by a newly assigned QAS. The guide will be a presentation of measures available for evaluating the status of the contractor's quality program in the defense electronics industry. To accomplish this, the following research questions will be studied:

1. How is quality defined in the industry? The quality philosophy used will influence the types of indicators used.
2. Which areas of the contractor's quality program should be emphasized in determining the status of the quality program? A brief review of MIL-Q-9858A reveals the many areas that contribute to a Quality Program. These areas are covered in the Common Indicators section in the literature review. This objective will identify those areas that will provide the best overall status of the contractor's quality program.

3. What quality indicators are currently being used by both the industry and the government? This information will provide the baseline indicators to be included in the guide. A listing and discussion of currently used indicators will be valuable to the QAS when choosing the quality indicators that are appropriate for his program.

4. What information is used as a basis for each indicator? Although two locations may use the same indicator (e.g., assembly line defects), the information base may differ (e.g., defects per man-hour versus defects per unit).

5. Who uses each indicator, and why? Collecting information for an indicator is not enough; the indicator must be used for it to be effective. This objective will identify the use of, and organizational level of personnel using, each indicator.

6. Which portion of the quality status does each indicator assess, and how comprehensive is the assessment? In recognition of the fact that no single indicator can assess the entire quality status, the coverage of each indicator will be discussed.

7. What indicators are not currently being used by the Air Force that may provide a better assessment of the quality status of the contractor? This is perhaps the most important objective, with the intent being to identify those indicators being used by industry but not being evaluated by the Air Force.

Scope

The objective of this thesis is to research and document the key quality assurance indicators used in the defense electronics industry. This documentation can be used by newly assigned officers in both the Aeronautical Systems Division (ASD) and the Electronics Systems Division (ESD) of the Air Force Systems Command (AFSC) who interface with defense electronics industry contractors in procuring products for the Air Force. The resulting indicators will aid the QAS in evaluating the quality status of the contractor.

II. Review of Literature

Organization of Review

This review begins with a discussion of quality as presented by experts in the field. Following this will be a short discussion of the types of quality problems and a review of the purpose and uses of quality indicators. These sections underscore the importance of quality indicators and examine the difficulty of evaluating quality. Finally, a review of the commonly used indicators will be presented, including those required by the Air Force.

Definitions of Quality

The dictionary definition of quality is given as a "peculiar and essential character" and a "degree of excellence" (27:944). These definitions are what the common person might perceive quality to be: the peculiar characteristics of an object that show a degree of excellence. Although widely accepted, this definition has great shortcomings when attempted to be used to measure quality.

Garvin has thoroughly researched the quality experts of the past several decades and presents their definitions of quality, as well as a definition he has developed. Garvin has found that Crosby refines the common definition suggested by Webster slightly by considering quality to be conformance to requirements (11:40-41). With this definition, any product that is built to conformance is considered to be a quality product; a Rolex watch built to specification is a quality watch, as is a Timex watch. Juran views quality in a different light, defining quality as fitness for use (11:41). Thus, a Timex may be considered lower quality than a Rolex if its accuracy or reliability is not acceptable. Juran's definition can be reduced to "quality lies in the eyes of the beholder" (11:41). Tuchman returns somewhat to the common definition when she references quality as being innate excellence (11:41). A person with this view might comment, "I may not be able to define quality, but I know quality when I see it." Garvin remarks that "excellence, according to this view, is both absolute and universally recognizable" (11:41).

Garvin categorizes Crosby's view (conformance to requirements) as being a manufacturing-based definition, Juran's (fitness for use) as a user-based definition, and Tuchman's (innate excellence) as a transcendent approach (13:25-28). He also acknowledges two other views of quality in his research. The product-based definition views quality as a very distinct set of variables or characteristics, and the product with more of these characteristics is of higher quality (13:25-26). Finally, he defines the value-based view as providing the most product at the best price (13:28). An individual with this final view would only consider a Rolex to be of higher quality if it kept time substantially more accurately than the Timex and if the difference in performance was worth the difference in price.

Not being satisfied with any of the above views of quality, Garvin has presented his own (11:41-42). His list of eight "dimensions of quality" are: performance, serviceability, reliability, conformance, durability, features, aesthetics, and perceived quality. "Each dimension is self-contained and distinct, for a product can be high on one dimension while being low on another" (11:42). In support of his definition, Garvin states:

> These eight dimensions of quality incorporate all three of the traditional definitions [conformance to requirements, fitness for use, innate excellence], as well as a number of other elements. In addition to being more inclusive, the framework suggests an important strategic consideration that might otherwise be overlooked: one can compete on quality in a number of different ways. (11:42)

Takeuchi and Quelch present their views on quality by informing the leader that "companies must be sure they are offering the benefits customers seek. Quality should be primarily customer-driven, not technology-driven, production-driven, or competitor-driven" (24:140).

While Garvin, Juran, Crosby, Tuchman, and Takeuchi each have their own views on what quality is, the Air Force also has a definition: the composite of material attributes, including performance features and characteristics, of a product or service to satisfy a given need (5:Encl 2). This definition, like Garvin's, incorporates several dimensions. The user-based (fitness for use) approach is included, as are the product-based (distinct set of characteristics) and the manufacturing-based (conformance to requirements) views. It is interesting to note that, in spite of a long-standing commercial trend to the contrary, the value-based (most product at the best price) view is not included as part of the official Air Force definition.

Peter Angiola, Staff Assistant, Defense Industrial Productivity and Quality Directorate, expands on this official Air Force definition:

> . . . we are shifting the emphasis on making a product successful as viewed from conformance to specifications, to conformance to correctly defined specifications. This makes the contractors responsible to achieve performance objectives rather than relying on the government to provide detailed specifications. This will hopefully lead to systems that meet performance objectives and mission needs rather than simply complying to specifications for legalistic reasons. (16:9)

In the terms defined by Garvin, this definition contains the essence of Juran's fitness for use along with Crosby's conformance to requirements. The reader should note the implication of the phrase "we are shifting" as used above is that conformance to correctly defined specifications is not the current requirement, but a goal. This is not so much a departure from the Air Force requirement that the product satisfy the specification as it is a refinement of the requirement to put the user's needs first.

MIL-Q-9858A suggests that a quality product, presumably as defined by the Air Force definition given above, is the end product. The specification does not, however, limit the contractor's responsibilities to merely providing "quality" products to the government. A system of acceptance sampling is closer to the intent of MIL-I-45208A, Inspection System Requirements, which is applied to less complex items. MIL-I-45208A relies more extensively on inspection of the product than on prevention of defects, the common view of quality from the past three decades. In contrast, the more comprehensive MIL-Q-9858A requires the contractor to have

> . . . an effective and economical quality program, planned and developed in consonance with the contractor's other administrative and technical programs . . . [assuring] . . . adequate quality throughout all areas of contract performance. . . . (6:1)

The requirement outlined above provides a starting point for defining what the Air Force expects a quality program to be. First, the program must be effective. Through use of the policies and practices of the quality program, the contractor should be able to ensure every deliverable meets all contract requirements. Second, the program should be cost effective. Much has been written about the costs of quality, and Crosby bases his quality philosophy on the fact that quality is, in fact, free. The government neither asks nor expects the contractor to spend a great deal of money on a program that will not benefit the contractor accordingly. Finally, the quality program should not be an organizational orphan. The responsibility for quality does not belong solely to the office with the title "Quality Assurance Department." To have a truly effective program, quality must pervade the organizational culture of all operations and functions within the company.

As is the case with most general definitions, the Air Force definition specifies only the general characteristics a quality program should include. No attempt has been made to say exactly what constitutes a quality program. No listing is provided which, when fulfilled exactly, would result in a quality program. The absence of a formal definition of a quality program challenges both the QAS and the contractor to evaluate the status of the quality program.

General Hansen, Commander of Air Force Logistics Command, has provided a definition of quality as it applies to his organization: "We must have the right goods and services--spare parts, engineering, and maintenance--in the right places at the right times . . ." (15:9). Basically a fitness for use philosophym this AFLC definition of quality partially reflects the implied Air Force definition given above, but tailors the definition to fit the mission of AFLC. Application of any quality definition, whether that definition was provided by the Air Force or by one of the quality gurus, may be unique for each organization.

Despite the absence of a formal definition of a quality program, measurement of that program is essential. As Lord Kelvin noted over a hundred years ago:

> . . . when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be. (1:23)

This view, hardly a recently developed philosophy, justifies and almost requires a formal definition of some kind be given to the contractor's quality program status. If the quality program status cannot be measured, knowledge about that status will continue to be "of a meagre and unsatisfactory kind."

Quality Problems

In a survey of "many" Fortune 500 companies, Leonard and Sasser identified the following perceived sources of quality problems (22:250):

Workmanship/workforce
Materials/purchase of parts
Maintenance of process equipment
Design of process equipment
Product design
Control systems
Management

Garvin came up with a similar list in his research (12:660). Each of these areas are discussed below to familiarize the reader with the types and diversity of potential quality problems.

The quality of workmanship suffers when the individual "on the floor," the one actually assembling the hardware, fails to follow work instructions or does a poor job in a manual process. Such quality problems can range from forgetting to install a washer to shorting a circuit with a poor solder joint.

Materials or purchased parts that don't meet standards ultimately affect the quality of the end product. A worker installing resistors on a circuit board must assume the parts supplied to him are suitable for the job. Regardless of the precision with which the resistor is mounted to the board, if the resistor doesn't perform properly, the quality of the end product will suffer.

Process equipment that has been pressed into extra service at the expense of routine maintenance is not likely to control the process at the required levels. If the accuracy of the process is to be the point of evaluation instead of final product inspection, the result can be a high proportion of nonconforming parts.

The design of the process equipment itself can contribute to the quality of the final product, or the lack thereof. Expecting a process to maintain tolerances beyond its capability is an invitation to quality problems; 100% inspection becomes the only recourse, a poor method of attempting to guarantee quality.

The design of the product must allow for the manufacturing and quality techniques used on the shop floor rather than those used in an engineering lab. Differing skill levels as well as differing conditions (time, lighting, humidity, temperature, available tools, etc.) must be considered.

Control systems are designed to insure the final product meets requirements. A control, such as the drawing release system used to release current, approved manufacturing and assembly drawings to the floor, can prevent the end item from meeting specification if the system is prone to error or slower than the process.

Finally, management can be the direct cause of poor product quality; studies have shown that management can control about 80% of defects (20:315). Being ultimately responsible for the decisions leading to the production of end items, they are also responsible if the wrong items are produced. An argument can be made that management is responsible for each of the areas listed above, but such a categorization may amount to little more than finger pointing and can hinder the resolution of problems.

With such a diversified list of perceived quality problems, from design to process to management, it is evident that no single indicator can adequately assess the status of a contractor's quality program.

Common Indicators

The Air Force requires several types of indicators in MIL-Q-9858A, Quality Program Requirements. Among these are measures of the quality and quality costs of purchased material, subcontracted work, drawings, engineering changes, measuring equipment, manufacturing work, fabrication work, and assembly work (6:1). Inspection and testing records must be kept, indicating types and numbers of deficiencies, and the action taken in connection with those deficiencies (6:3). Handbook H50, the guide to be used in conjunction with MIL-Q-9858A, also suggests that the records "indicate the percentage of items passing inspection or test and the quantities of acceptable and rejected items," and requires records be kept of "compliance or noncompliance with work instructions" (4:10). Handbook H50 further recommends that:

> . . . records of subcontractor quality assurance programs, of engineering approvals, of customer returns and cost records pertinent to acceptance of non-conforming materials [as] examples of the records required for an effective quality program. (4:10)

Finally, MIL-Q-9858A requires the contractor to have available "data associated with the costs and losses in connection with scrap and with rework necessary to reprocess nonconforming material to make it conform completely" (6:7).

The indicators identified above are from MIL-Q-9858A, a document intended for use as a guide to both the contractor and the QAS. The diversity and volume of indicators suggested or required by the government can be intimidating to the new QAS trying to determine the best way to evaluate a contractor.

Purpose and Use of Indicators

MIL-Q-9858A clearly states one of the purposes of maintaining quality assurance indicators: "Management regularly shall review the status and adequacy of the quality program" (6:2). This direction emphasizes that the existence of a quality program is not sufficient; the quality program must be a dynamic process subject to change as necessary.

Thinking of quality as a process ties strongly to one of the current philosophies of quality: design and manufacture quality into the product instead of trying to inspect quality into the product. This philosophy suggests the idea of controlling the process by which products are manufactured or developed. Exemplified by statistical process control, controlling the process within acceptable limits will help insure consistent product quality. Likewise, controlling the quality program within acceptable limits (its status and adequacy) will also help insure consistent product quality. The means to assuring the adequacy of the contractor's quality program, according to MIL-Q-9858A, is the "use [of] any records or data essential to the economical and effective operation of his quality program" (6:3). The handbook used in conjunction with MIL-Q-9858A, Handbook H50, places the responsibility for an adequate quality program squarely on the contractor:

> The contractor is solely responsible for the control of product quality and for offering to the government for acceptance only products determined by him to conform to contractual requirements. (4:1)

Handbook H50 continues, however, by stating that "the government's evaluation plan should apply to all aspects of a contractor's program" (4:1). Clearly the government is responsible for evaluating the contractor's quality status; such an evaluation is best performed using the tools developed by those most knowledgeable about contractor quality programs: individuals in the contractor's quality program office. While using the contractor's tools does not relieve the QAS's responsibility of verifying their appropriateness as quality status measures, it does prevent the QAS from reinventing the wheel.

The uses of indicators are as diverse as the types of indicators. MIL-Q-9858A requires "analysis of trends in processes or performance of work to prevent nonconforming product" (6:3). Quality cost data "shall serve the purpose of identifying the cost of both the prevention and correction of nonconforming supplies" (6:3) and to "facilitate sound decision making by contractors regarding their quality program" (4:12). "Adequate and economical control of [purchased] material" (6:4-5) is required, as is "final inspection and test of completed products [to] provide a measure of the overall quality of the completed product" (6:6). A Department of Defense Directive has a requirement that

> DoD components shall develop and manage a quality program to achieve the following objectives: assure mission and operational effectiveness and user satisfaction with DoD products; [and] assure that all services provided and products designed, developed, purchased, [or] produced . . . conform to specified requirements. (5:1)

This requirement expresses the use of a quality program "in-house" as well as at the contractor.

Garvin suggests that appropriate indicators might "capture the impact of incoming materials on processing times and test procedures" (10:6). This concern focuses on the fact that although all quality problems do not originate from within the contractor's plant, the contractor is not absolved from detecting and preventing these problems as well.

Review Summary

This chapter has examined several aspects of quality assurance indicators, beginning with the various definitions of quality. Experts have defined quality in many ways, viewing it as fitness for use, conformance to requirements, value for the money, innate excellence, or number of attributes present. The Air Force definition of quality includes several of these views. The contractors' definitions and measurements of quality will be examined in Chapter IV.

The variety of quality problems facing the industry were reviewed, and responsibility for defects was seen to lie not solely with the quality department, but primarily with management. There are many participants in maintaining top quality, including workers, the subcontracts department, design engineers, and manufacturing engineers. The range of defects provides a corresponding range of potential indicators, as shown in the discussion of common indicators. The areas that are actually monitored by the industry and by the government will be reviewed in the next chapters.

The purpose of quality indicators was identified as a means for the contractor to monitor the status of his quality program; the uses of indicators were reviewed, concentrating in such areas as trend monitoring, quality-cost evaluation, and purchased material appraisal.

The reader must keep in mind that the defense electronics industry revolves around the production of complex items, not capacitors and resistors. In many cases, the product can not be fully tested upon completion; only key dimensions of the product's operability can be evaluated at final test. This focus requires a process that will insure the quality of the end product and not one that will merely attempt to determine the final acceptability of that product.

The following chapters will discuss how two contractors in the defense electonics industry view quality and examine the emphasis placed on the various aspects of their quality programs. Examples of the indicators used will be presented, along with the reasoning for those indicators. The government view of quality will also be reviewed, with examples of the indicators used by QASs. Differing degrees of emphasis on the importance of areas of the quality program is expected due to the proximity of the evaluators to the production effort; the contractor is managing the program on a daily basis, while the QAS normally monitors the program on a weekly or monthly basis.

III. Methodology

This chapter describes in detail the methodology used for this research. First, the approach used will be broadly described, followed by a justification for that approach. The questions used to guide the discussions at each location will be covered in the interview guide. Finally, the population selected, the information collection plan, and the method of information analysis will be described.

General Approach

The following broad steps were used to reach the objective of providing the new QAS with a guide of possible quality assurance indicators:

1. Obtain quality indicators, by interview, from both contractor and Air Force personnel.
2. Discuss the information base and use of each indicator.
3. Propose a list of quality indicators based on what an ideal quality program might contain.

Justification of Approach

Interviews were chosen as the method of information gathering for several reasons. First, interviews provided the best opportunity to develop a guided, but unstructured, information base. The guided discussion allowed the inclusion of ideas and observations not originally considered during the planning of the interviews. Second, surveys were too limited in scope for this project, and receiving the information by mail presented the very real probability of incomplete information being submitted. Finally, telephone interviews would have involved an excessive amount of time on the part of the interviewee, again raising the probability of incomplete information.

Interview Guide

An interview guide was used to conduct the interviews due to the open-ended nature of the information desired. The guide included the questions posed in the research objectives, stated here in the format used at the contractor's facility. Several of the questions were of general use in obtaining background information about the contractor's facilities and quality program, and therefore do not address the issue of indicators directly.

1. How does your company define quality?
2. What are the components of your quality program?
3. What quality indicators are used by your company in assessing the quality status of a program?
    a. What information is used as the basis for each indicator?
    b. At what organizational level is each indicator used?
    c. Why/How is each indicator used?
    d. How adequate is the assessment?

4. What are the goals of your quality program?

   a. How do you know/measure when these goals have been achieved?

   b. Is continuous quality improvement itself used as a goal?

5. What role does quality play in the design process?

   a. Design for quality (design of experiments, robustness)?

   b. Design for producibility?

   c. Simplicity of inspection?

6. What quality tools are used (Taguchi's design of experiments, SPC, fixture control, automated processes, automated inspection, acceptance sampling)?

7. How is customer satisfaction measured?

8. What indicators are not currently required by the Air Force that would provide a better assessment of the quality status of the contractor?

Population

The intent of this research is to provide an index of quality indicators as currently used by the Air Force and selected contractors, not to provide a statistical list of indicators most commonly used. With this in mind, no attempt was made to gather a representative sampling of contractors or Air Force personnel.

From the government side, AFSC/ASD and AFSC/ESD were included due to their significant business with the defense electronics industry. The 2-letter offices responsible for quality assurance at each Division (PM at ASD, PL at ESD) were contacted and asked to prepare a presentation of the quality indicators and quality philosophies used at their locations.

From the industry side, only two contractors (ITT and Texas Instruments) were chosen due to time and fiscal constraints. They were selected based on personal experience and the experience of individuals in ASD's Directorate of Manufacturing and Quality Assurance as companies with excellent quality programs. The Vice-President for Quality at each of the selected companies was asked, first, for cooperation and, second, to prepare a presentation of the quality indicators and quality philosophies used in their companies.

As expected, industry was very eager to participate in this study. The information obtained was not used to assess the status of each company's quality program, but to provide a guide to quality indicators for the new QAS. The selected companies were proud of their quality programs and viewed this study as an opportunity to aid the Air Force in its evaluation efforts, a benefit to the industry when newly assigned QASs are involved.

Data Collection Plan

The type of information desired involved a full day at each location. Use of a tape recorder was attempted, but found to be either ineffective (participants were reluctant to speak openly while the recorder was running) or prohibitted by the security at the location. Consequently, hand-written notes were taken during the interviews. This method of collecting information was certainly not the most efficient, but was necessitated by the situation. Each location did supplement the interview, however, by supplying hardcopies of the indicators of interest (presented in Chapter IV).

Analysis

As noted in Chapter I, the intent of this thesis is to provide a guide to quality indicators to be used by officers newly assigned as Quality Assurance Specialists (QASs). The nature of the population selected and the intent of the study dictated that a statistical evaluation would not be beneficial. Instead, the merits and shortfalls of the indicators contributed by each location were presented and discussed. Based on a review of the indicators' merits and shortfalls, and on the observations offered by each location, the elements of an ideal quality program were presented. The elements of the "ideal" quality program are intended to serve as the guide to quality indicators.

This list of indicators is only intended to serve as a starting point for the QAS. The reader is encouraged to evaluate the indicators and discussions presented in light of his or her current program requirements. The analysis includes elements an ideal quality program might contain, based on the quality indicators and observations presented by the four locations, but in no way is the analysis intended to limit the QAS to the indicators presented.

IV. Findings

Organization of Findings

This chapter presents the results of the interviews with quality managers from ITT, TI, ESD, and ASD. Since the intent of this thesis is to provide a guide to quality assurance indicators and not to evaluate the quality programs of the contractors or product divisions studied, not all the indicators or programs used at a location will be presented. Identical indicators used at more than one location will only be discussed once, with minor variations to be discussed in Chapter V. This is not intended to diminish the importance of the indicators at the other locations, but rather to provide a concise presentation of the wide variety of indicators used.

Numerical values and program identifiers have been removed from the tables and figures contributed by the contractors. Actual values are proprietary and would be of no use to the QAS deciding on which indicators to use for his or her program. The indicators presented by ESD are based on fictitious data and do not represent the status of either ITT or Texas Instruments.

Each interview presentation will begin with background information, providing not only some information about the products managed at the location, but also an insight into the operating philosophy at the location. The next, discussion focuses on the quality indicators used by that location, providing the reader with examples of quality assurance indicators. Finally, observations made by the respondents in the area of quality or quality management are presented. These observations should help the QAS in evaluating the indicators presented.

Detailed discussion and analysis of the information will be presented in Chapter V.

<u>ITT Avionics Division (ITTAV)</u> (23)

<u>Background</u>. ITTAV is a division of ITT Defense Corporation, the parent organization of all ITT divisions doing business with DoD. Located in Nutley, New Jersey three programs comprise the major focus at ITTAV. The largest of these programs is the AN/ALQ-165 Airborne Self-Protection Jammer (ASPJ) which is used on many airframes, including the Air Force F-16. The second major ITTAV program is the upgrade and production of ALQ-136 defensive electronic countermeasures systems for use on the Army's AH-64 Apache helicopters, the OV-1, and potentially on the V-22 Osprey. The ALQ-172 jammer, being used on Air Force B-52s and certain C-130s, is the final major program, and is nearing the last years of its production buy. The users of these systems have expressed their satisfaction with ITTAV's products. (14:23)

ITTAV defines quality as conformance to specification, where the specifications are dictated by the contractual relationship between the government and ITTAV. This definition would be expected since conformance to specification is what they are paid to do. Despite this required definition, ITTAV attempts to identify contractual inconsistencies, deficiencies, and unreasonable requirements, especially at the system level. Should parameters be omitted by the government, or be at a level considered too lax by ITTAV, the company's minimum standards are used as appropriate. In addition, ITTAV management advocates the "next process as customer" philosophy for internal operations.

Quality Indicators.

Statistical Process Control. ITTAV employs several methods of maintaining quality in the production environment, some of which can also be defined as quality indicators. One of these methods is Statistical Process Control (SPC). This system for monitoring the status of a process can reveal any tendency for the process to leave the prescribed norms, ideally allowing corrective action to be taken before the product is affected.

ITTAV currently has twenty applications of SPC, including soldering (wave, hand, bar, and vapor phase), bench assembly, conformal coating, and wirebonders. The SPC data are plotted real-time by the process operators, while analysis of the SPC charts is done weekly by supervisors and process engineers (the operators flag undesirable trends if they are noted during the week). The goals in this area are defined by the upper and lower control limits calculated for the SPC chart. Although contractual requirements require 100% inspection in some cases, SPC is still being performed to observe trends and prevent problems.

Design. In the area of design, ITTAV has a reliability, maintainability, safety (RMS) group using a Reliability, Availability, Maintainability - Computer Aided Design (RAM-CAD) system to assist in the design of circuits. Building blocks (circuits common to particular applications) are designed and evaluated for RAM values. These building blocks are then evaluated for trends in RAM values, and field data are correlated with lab data to verify the values. No specific numeric goals are set in this area, rather a continuous improvement goal is implied.

Vendor Rating. A vendor rating system reports monthly on the quality of vendors supplying ITTAV. The system is based on data from incoming inspection, source inspection, survey results performed by the Vendor Quality group, and line rejects discovered during assembly and test. A complexity factor is assigned based on the unit price of the commodity: a low unit price results in the highest complexity factor (1.0), while a high unit price results in the lowest complexity factor (0.5). The actual rating for vendors with multiple products is done according to the following formula

$$\frac{LR(A) * CF(A) + LR(B) * CF(B) + \ldots + LR(n) * CF(n)}{LI} * 100 = \text{Rating } (\%) \qquad (1)$$

where

LR(i) = lots of product i rejected
CF(i) = complexity factor of product i
LI = total lots inspected

Alphabetic ratings are applied to vendors based on the rating percentages as determined by Eq (1):

Rating A (recommended) - 5% or less
Rating B (acceptable) - > 5% but < 15%
Rating C (unsatisfactory) - 15% or greater

A vendor may also receive an automatic C rating as a result of unsatisfactory survey results, failure to reply to a corrective action request (CAR), or unsatisfactory reply to a CAR.

Summary data are presented in two formats. Table 1

Table 1. Vendor Ratings by Commodity Category

TOTAL VENDORS RATED
MARCH, 1989

	A	%	B	%	C	%	TOTAL
MECHANICAL ASSEMBLY							
ELECTRICAL ASSEMBLY							
MECHANICAL COMPONENTS							
ELECTRICAL COMPONENTS							
RAW MATERIAL							
MISCELLANEOUS							
TOTAL							

presents the data by commodity category, giving the number of vendors with a given rating as well as the percentage of vendors with that rating. The commodity categories were chosen by ITTAV as a means of grouping the vendors by the same or similar types of items. Figure 1 presents the data without regard to commodity category, showing only the percentage of vendors with a given rating.

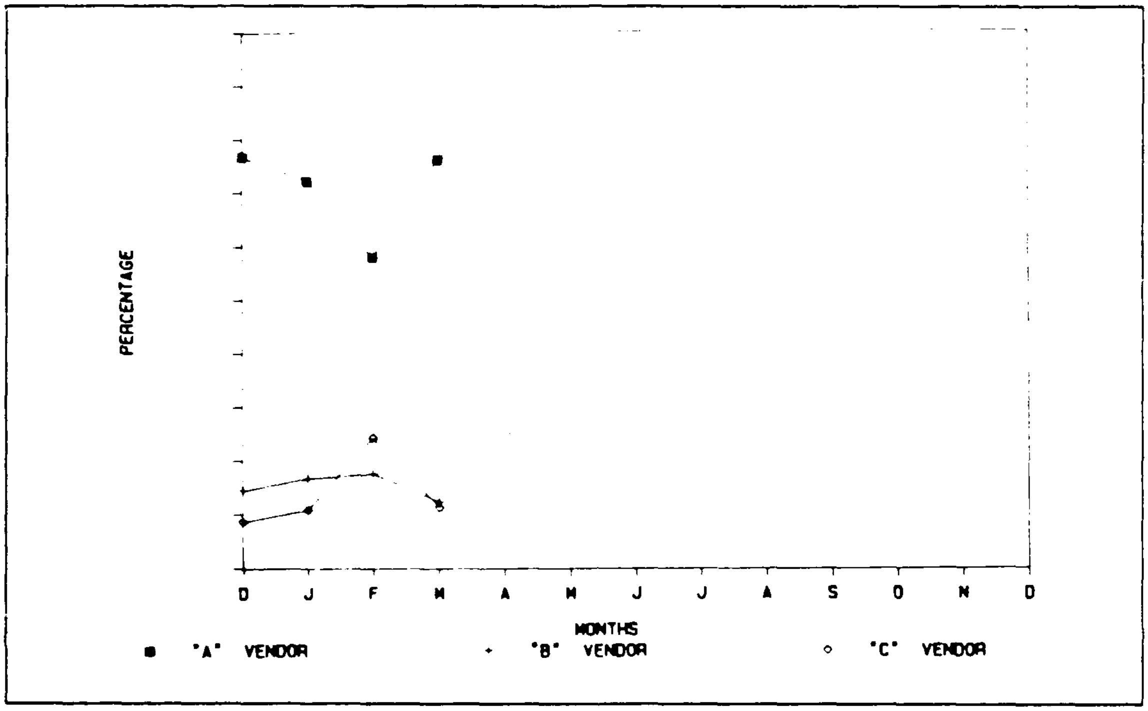

Figure 1. Monthly Performance of Active Vendors

Quality Costs. An ITTAV report details

> . . . the basic concept of quality costs [as] recognition and organization of certain costs related to quality to gain knowledge of their major contributing segments and the direction of their trends. (18:1)

To this end, they break quality costs into the traditional categories of prevention, appraisal, and failure.

ITTAV-wide total quality cost data is presented in a monthly report as a cumulative percentage of sales, i.e., quality costs year-to-date vs sales year-to-date, with a goal set by management based on past performance (Figure 2).

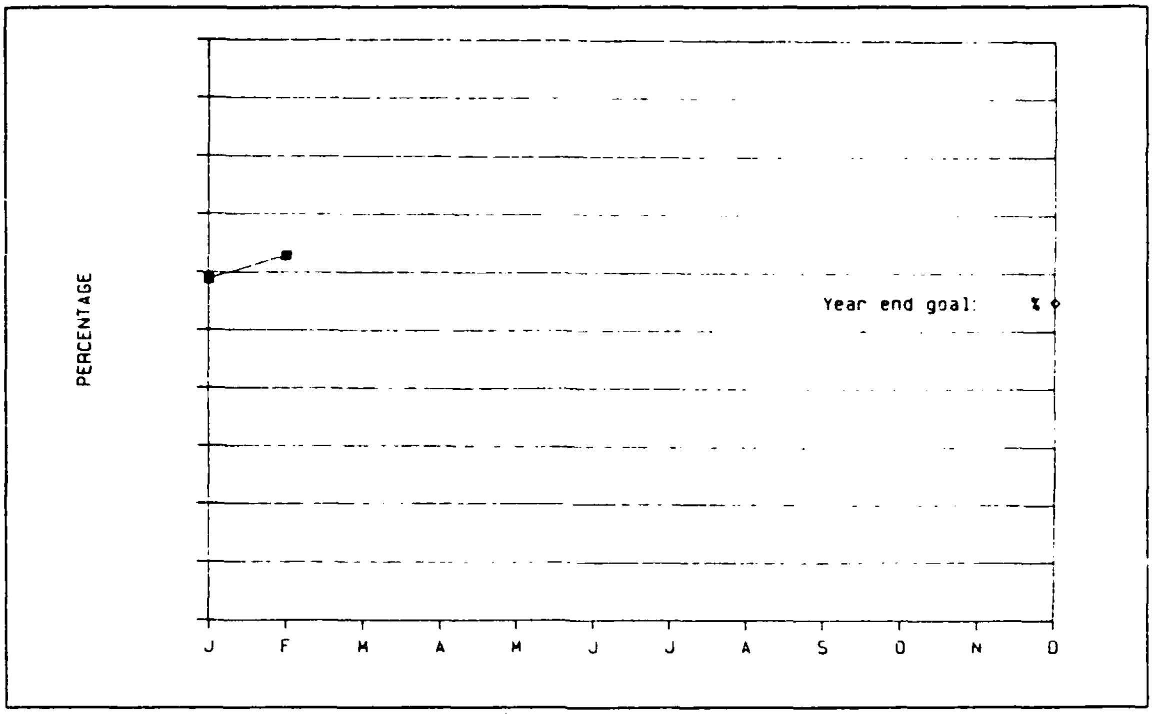

Figure 2. Quality Costs vs. Sales, Year-to-date

This data is also tabulated by presenting the costs in the traditional categories, as well as subcategories, and detailing the final values from the previous year, year-to-date, and current month (Table 2). The values are available in dollars and as a percentage of the quality control budget. Being a monthly report, the cost of quality (COQ) information is primarily used as a tool for keeping upper management aware of cost data.

In addition to the division-wide data presented in Figure 2 and Table 2, program-specific data are also available for selected categories by month (Table 3) and year-to-date.

Table 2. Quality Costs, YTD and Current Month

CATEGORY	YEAR END (1988) % QC	YEAR TO DATE ACTUAL ($000'S)	YEAR TO DATE % OF ACTUAL QC	CURRENT MONTH ACTUAL ($000'S)	CURRENT MONTH % OF ACTUAL QC
PREVENTION					
ASSURANCE ENGINEERING					
QUALITY ADMIN. SERVICES					
TRAINING & MOTIVATION					
TOTAL PREVENTION					
APPRAISAL					
INCOMING INSPECTION					
ALL OTHER INSPECTION					
TEST					
STANDARDS & CALIBRATION					
SUPPLIER QUALITY					
TRAVEL EXPENSE					
MAT'LS. & EVALUATION LAB					
PRODUCT ACCEPTANCE					
MICROELEC. QUALITY INSP.					
TOTAL APPRAISAL					
FAILURE					
REWORK LABOR					
ECR/ECN LABOR					
SCRAP					
WARRANTY					
TOTAL FAILURE					
TOTAL QUALITY COSTS ($000)					
SALES ($000)					
QUALITY COSTS (TOTAL) AS A % OF SALES					

Table 3. Monthly Failure Costs

PROGRAM/RESPONSIBILITY		TEST (FUNCTION 52)		FABRICATION (FUNCTION 90)		ASSEMBLY (FUNCTION 60)		PCB FABRICATION (FUNCTION 65)		INSPECTION (FUNCTION 53,91)		MICROELECTRONICS (FUNCTION 48)			FIELD	
NAME	QUALITY PROJ/ CTRL ENGNR	ECR/ECN	REWORK	ECR/ECN	REWORK	ECR/ECN	REWORK	ECR/ECN	REWORK	ECR/ECN	REWORK	ECR/ECN	REWORK	SCRAP	WARRANTY	TOTALS
ALQ-136 (ALL)																
SPARES																
ALQ-117/172/PAVEWIDY																
ASPJ FSD																
ASPJ PV																
SLQ-34/SLR-22																
OE-273																
MISC. PROGRAMS																
SUB TOTALS:	ECR/ECN															
	REWORK															
	SCRAP															
	WARRANTY															
	TOTALS															

Graphs of quality cost data are presented in numerous formats throughout the monthly report: rework costs by program (Figure 3), rework as a percentage of direct labor (Figure 4), rework costs by function or cause (Figure 5), rework by function as a percentage of function direct labor dollars (Figure 6), engineering change request (ECR)/ engineering change notice (ECN) costs by program (Figure 7), ECR/ECN costs as a percentage of direct labor dollars (Figure 8), ECR/ECN costs by function (Figure 9), ECR/ECN by function as a percentage of direct labor dollars (Figure 10), and scrap costs by program (Figure 11).

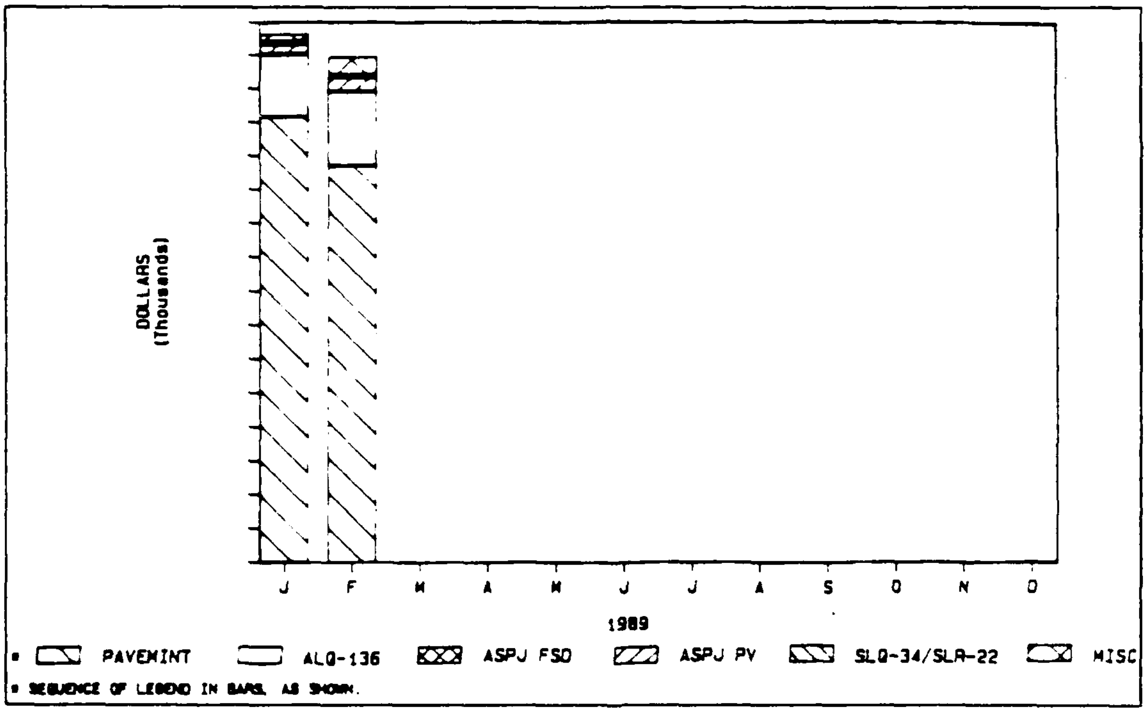

Figure 3. Rework Costs by Program

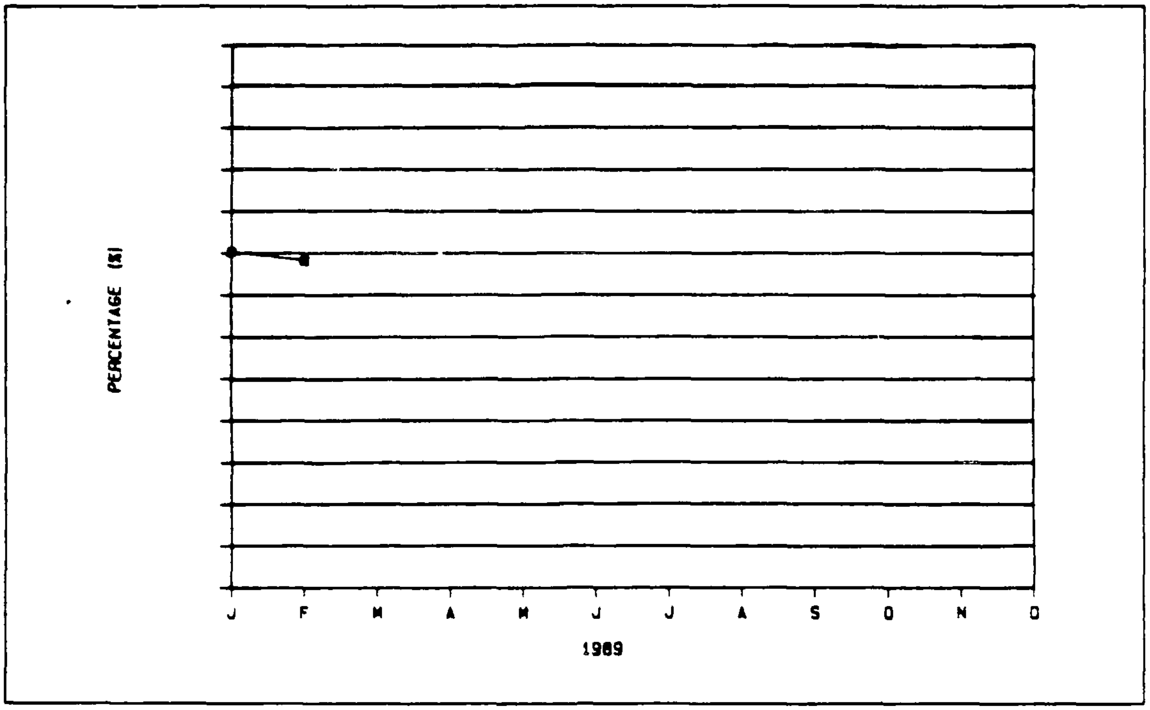

Figure 4. Rework as a Percentage of Direct Labor Costs

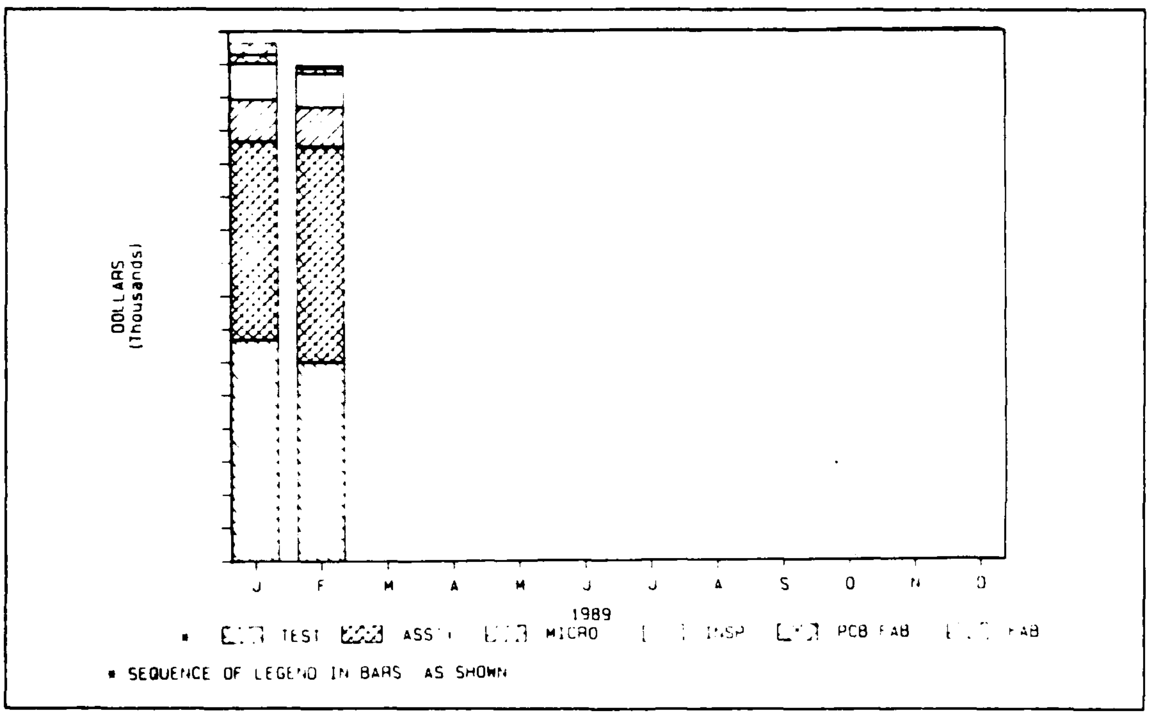

Figure 5. Rework Costs by Function

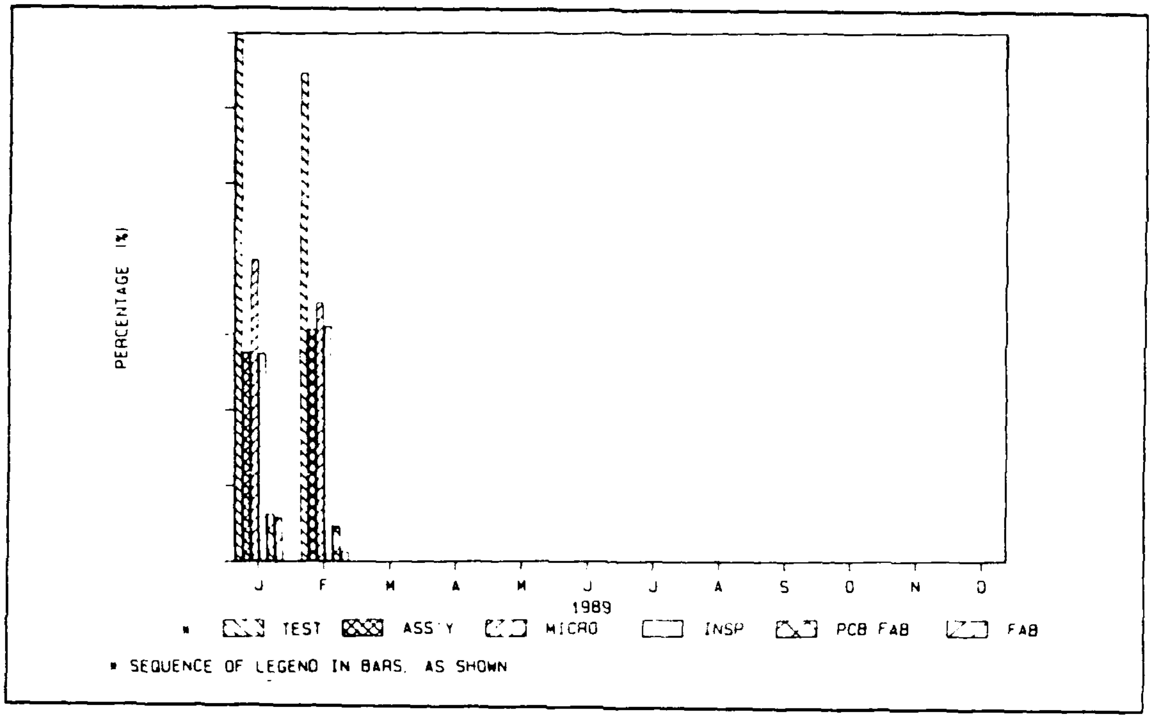

Figure 6. Rework by Function as a Percentage of Direct Labor Dollars

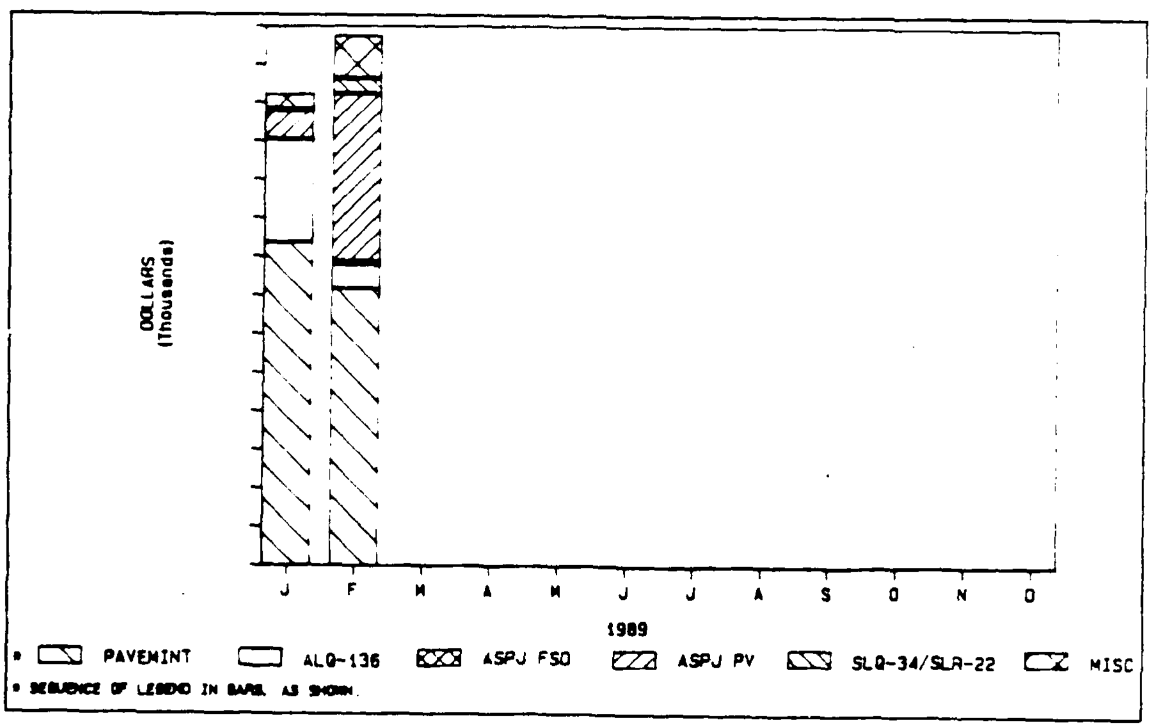

Figure 7. ECR/ECN Costs by Program

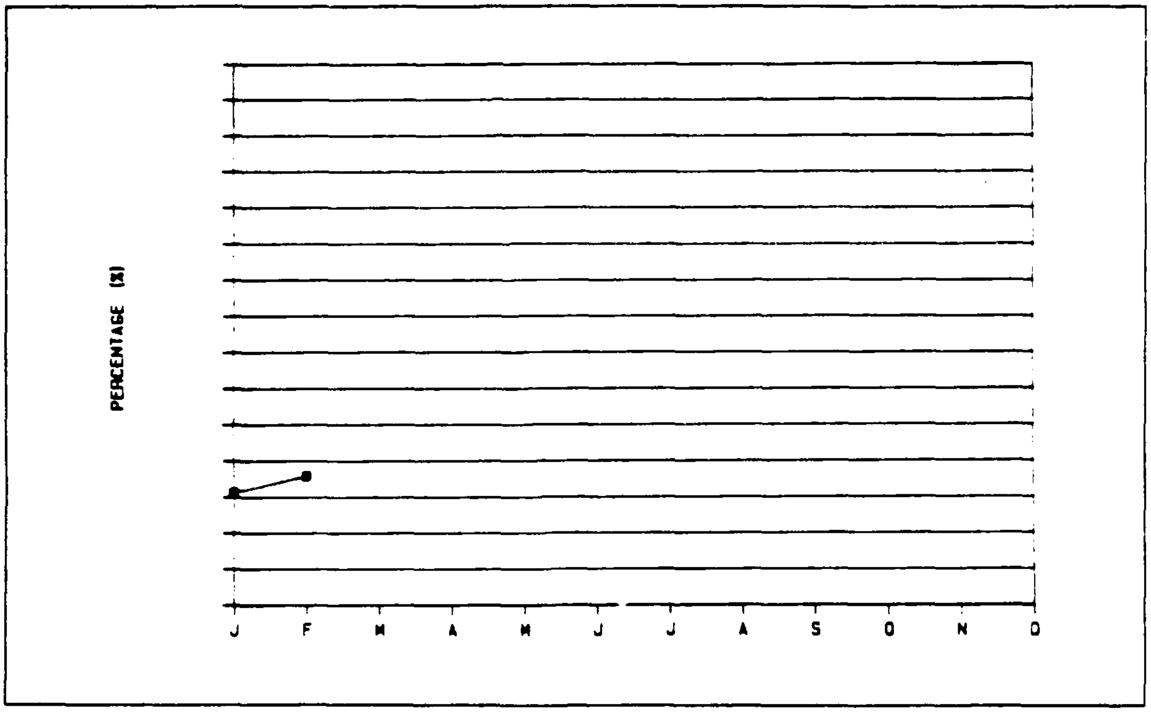

Figure 8. ECR/ECN Costs as a Percentage of Direct Labor Dollars

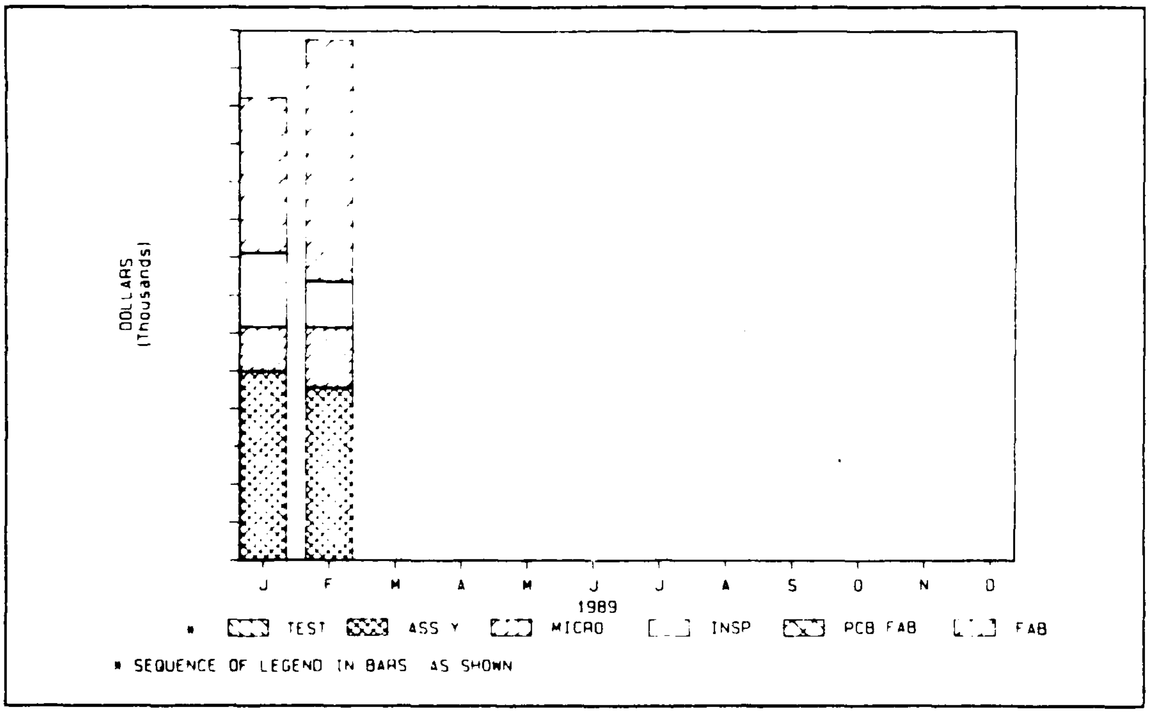

Figure 9. ECR/ECN Costs by Function

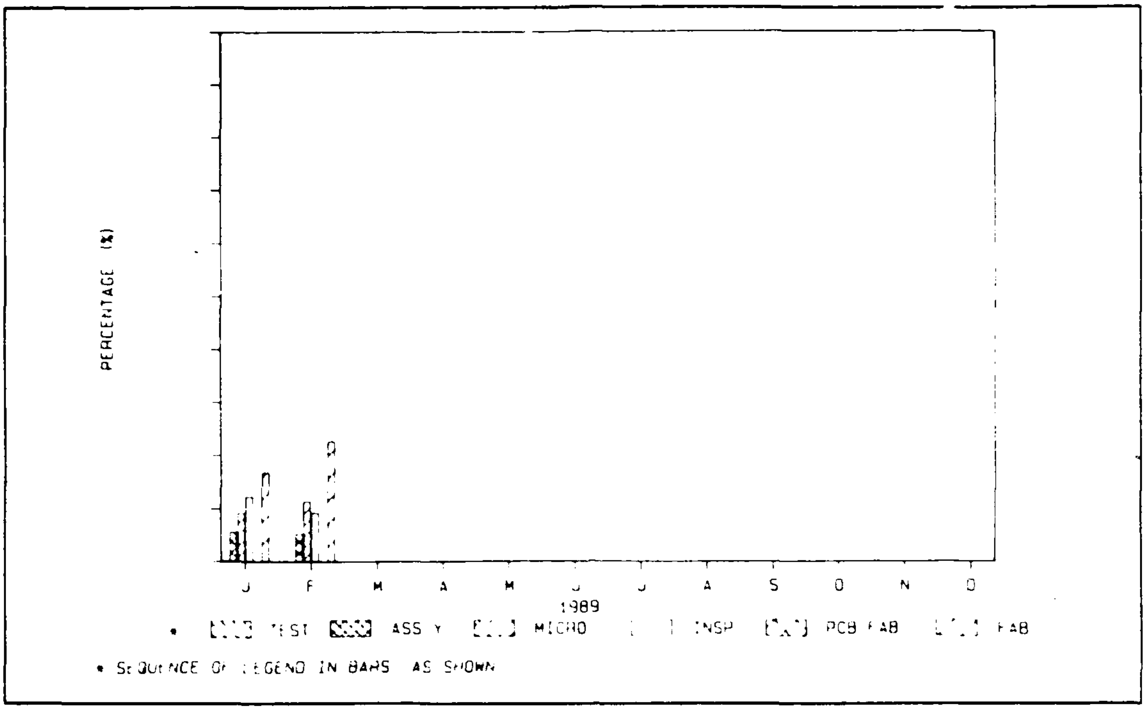

Figure 10. ECR/ECN Costs by Function as a Percentage of Direct Labor Dollars

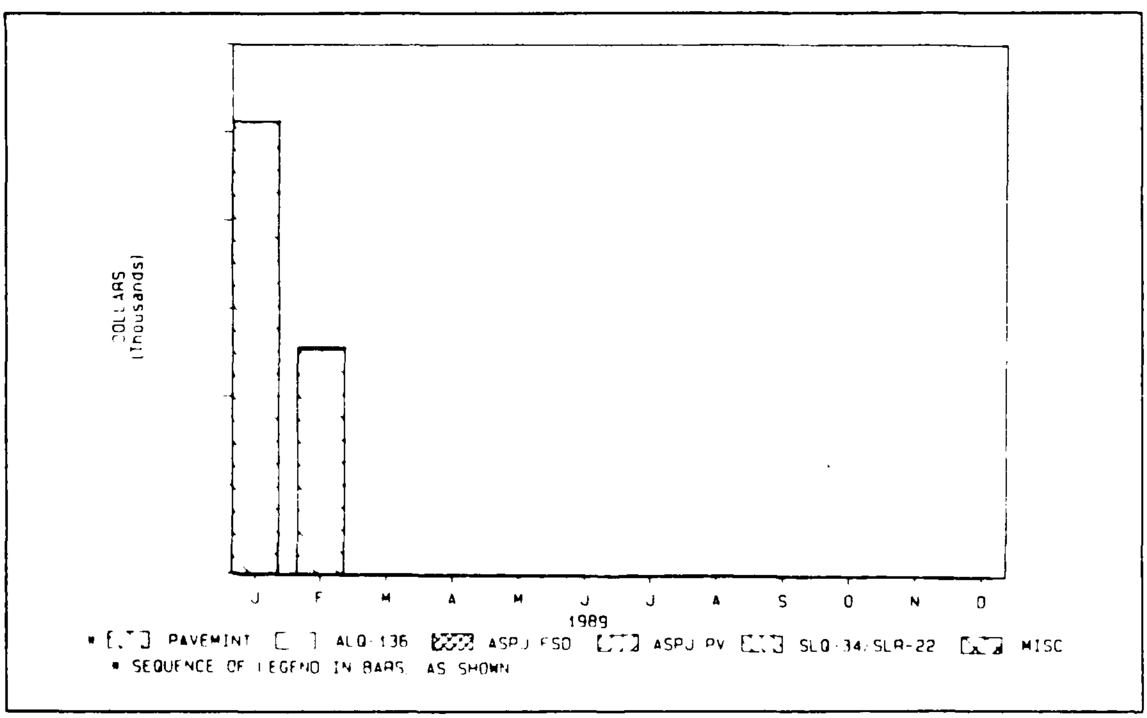

Figure 11. Scrap Costs by Program

The monthly report concludes by identifying the major contributors to ECR/ECN, rework, and scrap costs (Table 4).

Table 4. Major Contributors to Costs

PROGRAM	ECR/ECN ASST/ PART NO	ECR/ECN DOLLARS	REWORK ASST/ PART NO.	REWORK DOLLARS	SCRAP ASST/ PART NO.	SCRAP DOLLARS
ALQ-136			2623875			
			919885			
			2623877			
PAVEMINT			2628210		2488960	
			2624866		3130590	
			2625102		2488782	
			2627127		2628214	
			2638201		2487424	
			2489902		2622516	
			2626747		2138771	
			2624702		3130725	
			2625246		M38510/31504BEB	
			2625248		2624881	
			2628204		2612716	
			2630179		2625267	
TOTAL DOLLARS						

A discussion of Figure 5 will show how these graphs could be used by the QAS in monitoring the company's control of the program. Test and assembly are evident as the dominant causes of rework. Although the total rework costs have declined in February, the proportion of rework due to test and assembly has actually risen. This area should merit the majority of the QAS's time when discussing rework costs with the contractor and determining the causes of the rework required.

<u>Observations</u>. Inspection of product can be subjective, due to one person seeing what another doesn't see, even

under identical conditions. This grey area between acceptable and unacceptable makes defining quality difficult, a situation which can be illustrated clearly in the area of soldering. Even the titles of potential solder defects suggest ambiguity: solder not smooth and shiny, insufficient solder, excessive solder (lead discernable), excessive solder (lead not discernable), and poor wetting. Consequently, the number of defects attributed to a given product may depend on the person counting the defects, regardless of the experience level of that person.

Cost savings in quality assurance are often difficult to evaluate, especially in the Return-on-Investment terms usually used in business. Improvements in a process, such as computerizing data collection to allow more timely trend detection, must be shared by both quality and manufacturing, making the contribution by quality difficult to pinpoint. Perhaps the easiest, but least practical, way of determining the savings due to quality improvements and enhancements would be to remove or "turn off" those changes. Long-term removal of an established computerized system would not pinpoint the savings due to the enhancement, but would instead reduce productivity below the pre-enhancement level.

It is possible to show the aggregate effect of quality programs over time by observing an increase in the quality of the final product. Trying to measure the effects of a single "intangible" program such as a quality improvement program or a RMS design effort is more difficult. This difficulty hampers the effort to develop indicators on the effectiveness of intangible programs. Tangible programs, such as raising yields or lowering defect rates, constitute the majority of the measures identified in this research.

Texas Instruments, Radar Systems Division (TI/RSD) (3)

Background. TI/RSD is a division of Avionics Systems, which in turn belongs to the TI Defense Systems & Electronics Group. Located in McKinney, Texas, there are three major Product Customer Centers (PCCs) at TI/RSD: LANTIRN/MMR, F-111, and NAV/ATTACK. The manager interviewed at TI/RSD was responsible for the F-111 PCC; consequently, the information provided during this interview applies primarily to the F-111 product line. Although some of the techniques and quality measures may apply to the other product lines as well, the product lines are separate and independently managed, and the responsible quality assurance personnel determine the most appropriate indicators for use in their programs (see Observations below for further discussion on this point).

TI/RSD espouses a dual quality philosophy including both the satisfaction of contractual requirements and the satisfaction of the customer, both the final customer and the next process. To supplement contractual requirements, TI/RSD uses requirements commonality within work areas such as electrostatic sensitive device (ESD) handling and soldering. Requirements commonality dictates that all processes within an area conform to the same requirements, based on the most stringent contractual requirements in that area. For example, in a room where ESD integrated circuits are handled, even non-ESD integrated circuits will be handled as if they required ESD precautions. Although a quality extreme, this philosophy simplifies the detection of handling errors and reduces the chance of ESD integrated circuits from being damaged due to negligence.

Added emphasis on doing the job right the first time is given by TI/RSD's use of the Material Review Board (MRB). The MRB is typically used to disposition a nonconforming item into one of several categories: rework, standard repair, return to vendor, scrap, use-as-is, or non-standard repair. Since the latter two dispositions require government approval, TI/RSD has eliminated them as options, thereby emphasizing conformance to requirements.

Project 52 is a prgram emphasizing regular weekly deliveries rather than making all shipments at the end of the month. The Project has helped reduce errors by avoiding the tendency to rush a lot of work through in a month-end rush to ship finished product.

Quality Indicators.

Inspection and Test Yields. A generalized yield chart (Table 5) is used regularly by the Quality and Reliability Assurance (QRA) analyst, the individual responsible for monitoring the daily quality of a Product Customer Center. This chart identifies the parts by number and by the printed wiring board (PWB) on which they are used, detailing the quantity of items having passed through

Table 5. Generalized Yield Chart

		BQC				FQC					TOTAL
PART NO.	PWB DESCRIPTION	QTY	YLD	PBAR	LCL	QTY	YLD	PBAR	LCL	....	YIELD
XXXXXXXX	XXXXXXXXXXXXXX	XXX	XXX	XXXX	XXX	XXX	XXX	XXXX	XXX		XXXXX
XXXXXXXX	XXXXXXXXXXXXXX	XXX	XXX	XXXX	XXX	XXX	XXX	XXXX	XXX		XXXXX
XXXXXXXX	XXXXXXXXXXXXXX	XXX	XXX	XXXX	XXX	XXX	XXX	XXXX	XXX		XXXXX
.	.	.	.	.	.	.	.	.	.		.
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.			.	.	.	.	.	.	.		.
		TOTAL	AVG	AVG	AVG	TOTAL	AVG	AVG	AVG		
			YLD	PBAR	LCL		YLD	PBAR	LCL		
		XXXX	XXX	XXXX	XXX	XXXX	XXX	XXXX	XXX		

a given inspection or test (see list below), the yield, and the SPC attribute values p-bar and lower control limit. This information is further tabulated into total yields for each part number and average values for each inspection or test. The yield information is included for the following:

- PWB-level inspection after the PWB has been component stuffed
- PWB-level inspection after the PWB has been flow soldered
- PWB-level circuit test after flow solder
- PWB-level inspection of manual assembly operations
- PWB electrical test before thermal shock
- PWB electrical test after thermal shock
- PWB-level inspection after the PWB has been encapsulated
- LRU (Line Replaceable Unit) assembly electrical test before environmental stress screening
- LRU-level environmental stress screening
- LRU assembly inspection before acceptance test
- LRU assembly acceptance test

Table 5 is an abbreviated version of the chart actually used by the Quality and Reliability Assurance (QRA) analyst, using "BQC" and "FQC" as identifiers for the first two categories identified above.

This indicator is used to spot areas where additional attention must be focused. Part numbers with a low yield can be identified rapidly, as can those parts with p-bar values lower than the average. See the Analysis (Chapter V) for a caution when using this indicator.

First-pass yields are identified by LRU, detailing the trend over a year. Figure 12 shows the percent yield for acceptance test, with other categories including

LRU-level
- Unit test before burn-in
- Burn-in (environmental stress screening)
- Unit test after burn-in
- Final quality control before acceptance test
- Quality control configuration inspection

PWB-level
- Board-level inspection
- Flow solder quality control
- PWB circuit test
- Electrical assembly quality control
- PWB unit test before thermal shock
- PWB unit test after thermal shock
- Encapsulation quality control

Defects. Line Replaceable Unit (LRU) assembly-level defects are accumulated monthly and presented graphed to identify defect quantities by LRU sequence number for each LRU. Figure 13 shows such a graph for test defects, with similar graphs prepared for inspection defects and standard repair procedure (SRP) usage. Since the graphs represent LRU assembly-level information, the defect count

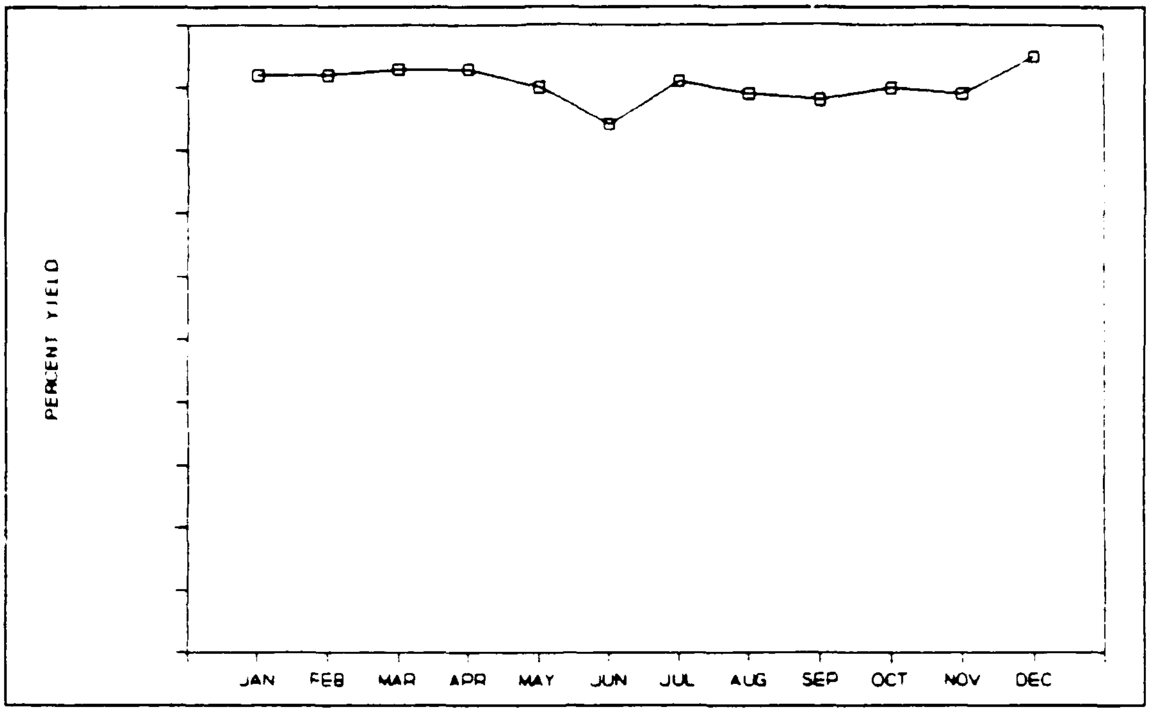

Figure 12. Acceptance Test Yield

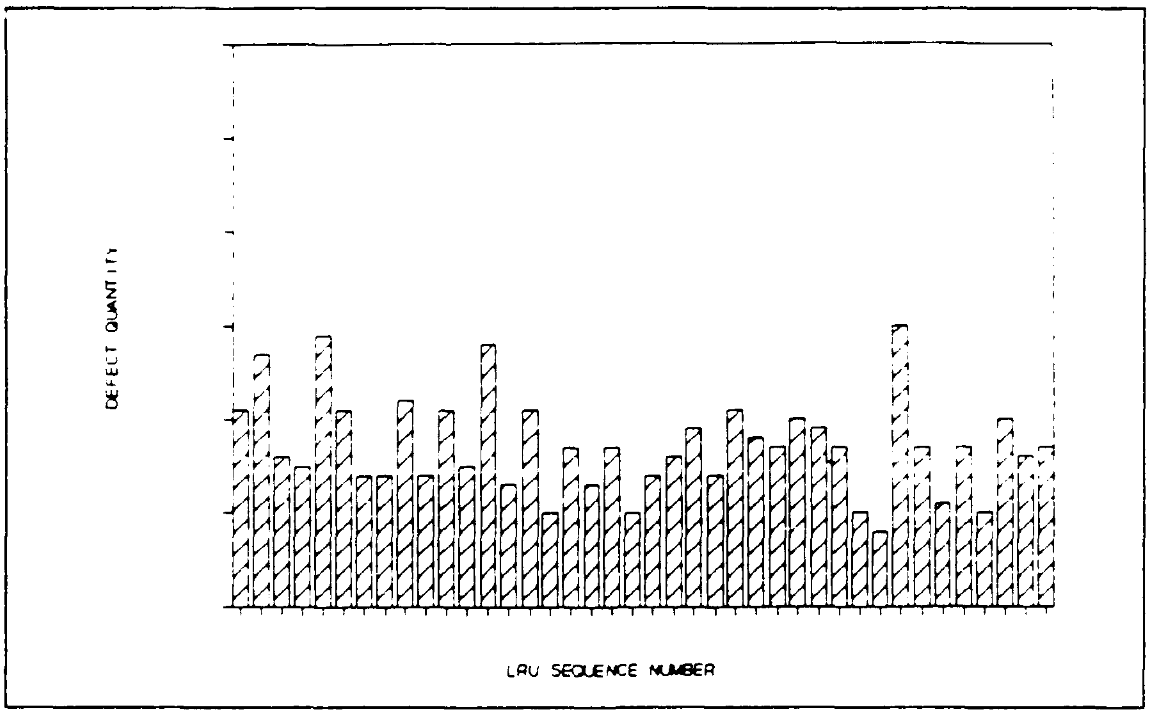

Figure 13. LRU Test Defects

includes defects at the printed wiring board and shop replaceable unit levels as well. The standard repair procedure version of this graph does not actually identify a defect quantity, but instead identifies the number of times SRPs were used in correcting defects.

Specific areas of interest are tracked separately by TI/RSD. The solder area, for example, plots component lead solder defects weekly (Figure 14), as well as flow solder defects, and touch-up solder defects.

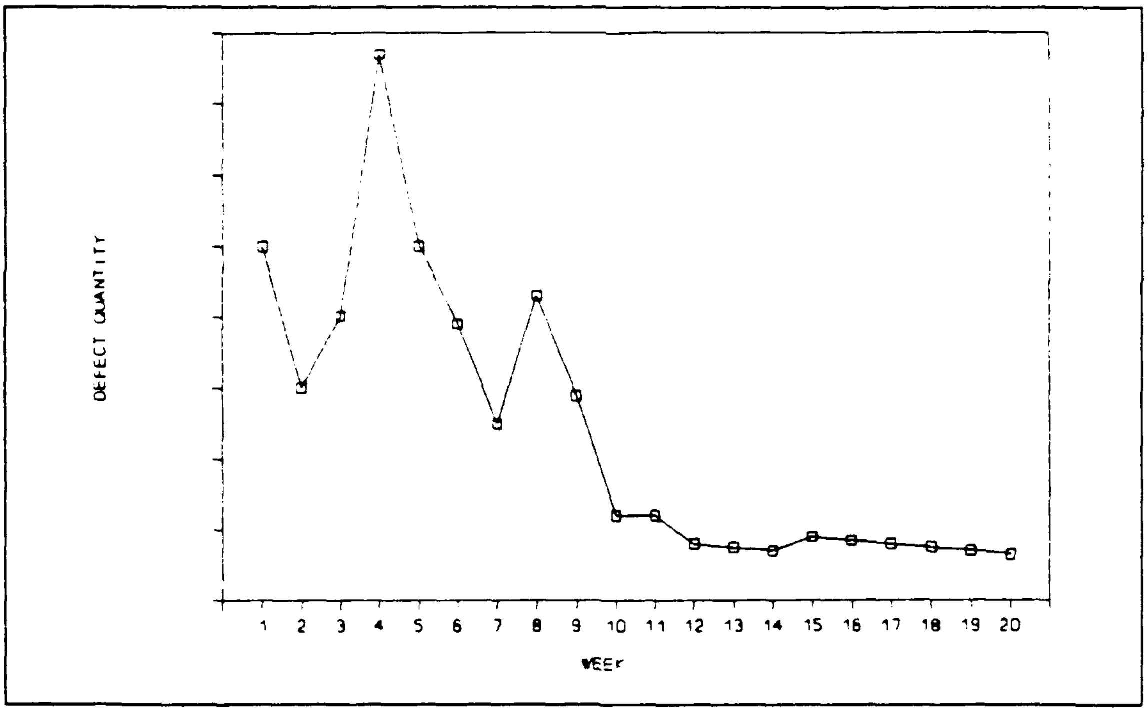

Figure 14. Component Lead Solder Defects

TI/RSD also uses what they refer to as "pedigree graphs" to identify the long-term defect history of a given LRU (including all defects due to paperwork, documentation, workmanship, test procedure, planning, work instructions, design, configuration, handling, and cosmetics). The pedigree data is accumulated from the monthly data described above and represented as either a discrete-point graph (Figure 15) or as a 25 unit cumulative average graph (Figure 16). Both of these graphs are useful for displaying defect trends to upper management. The pedigree graphs are also available showing only inspection defects or only test defects.

Pareto analysis is used to identify those areas requiring the most immediate attention. Figure 17 is an example of a graph detailing the PWBs and SRUs with the most defects per unit, while Figure 18 represents similar information focusing on the defects occurring most often.

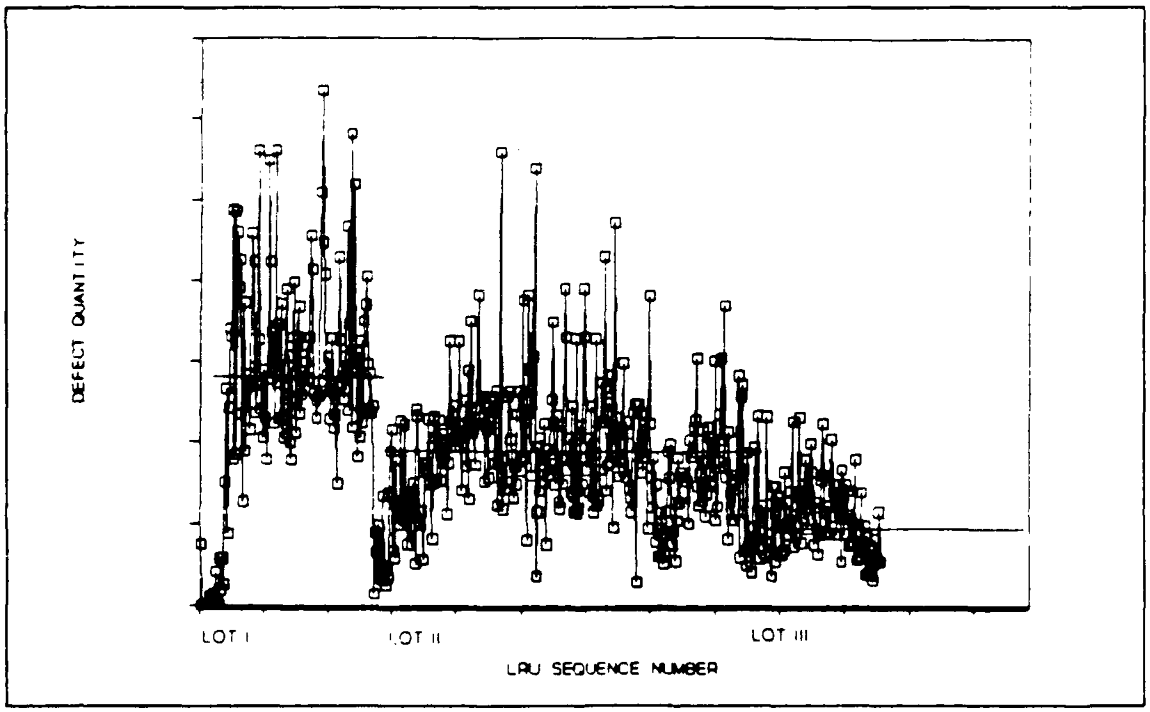

Figure 15. Discrete Point Pedigree

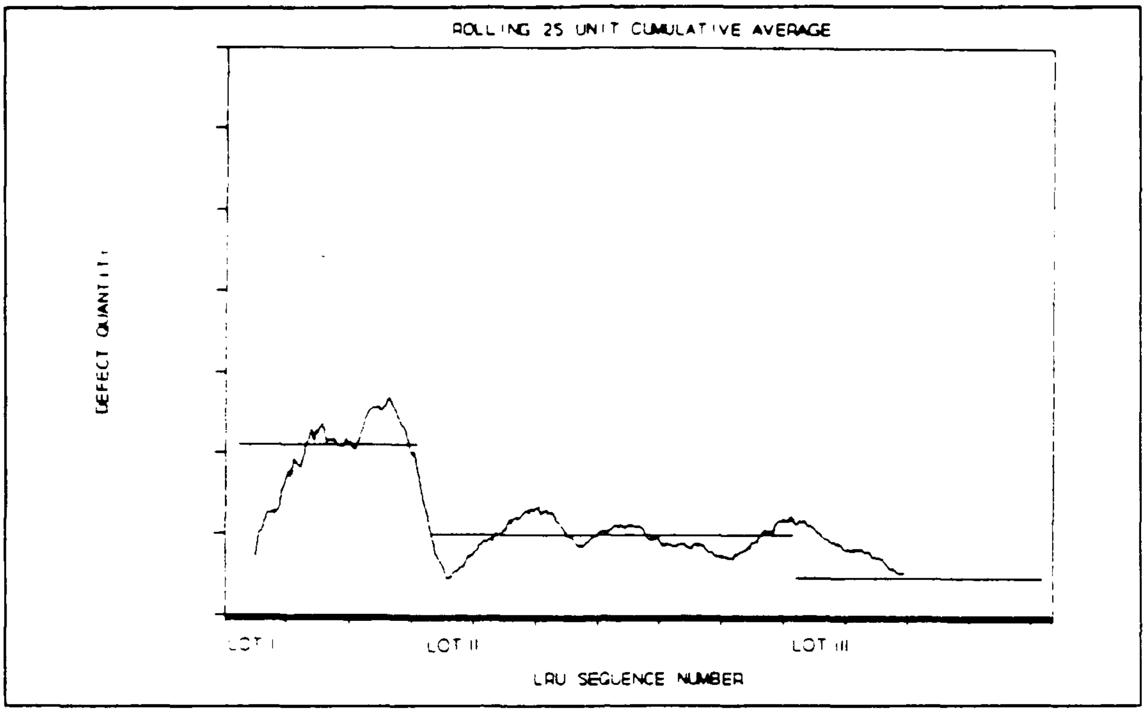

Figure 16. Cumulative Average Pedigree

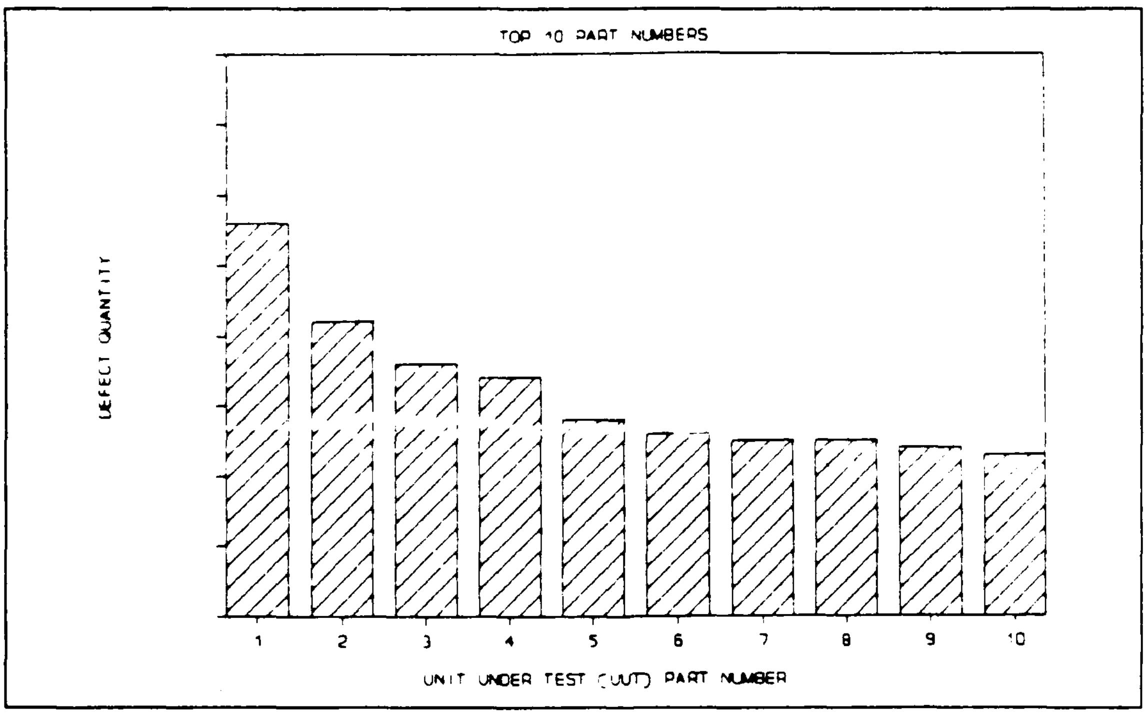

Figure 17. Pareto Analysis for Defects per PWB/SRU

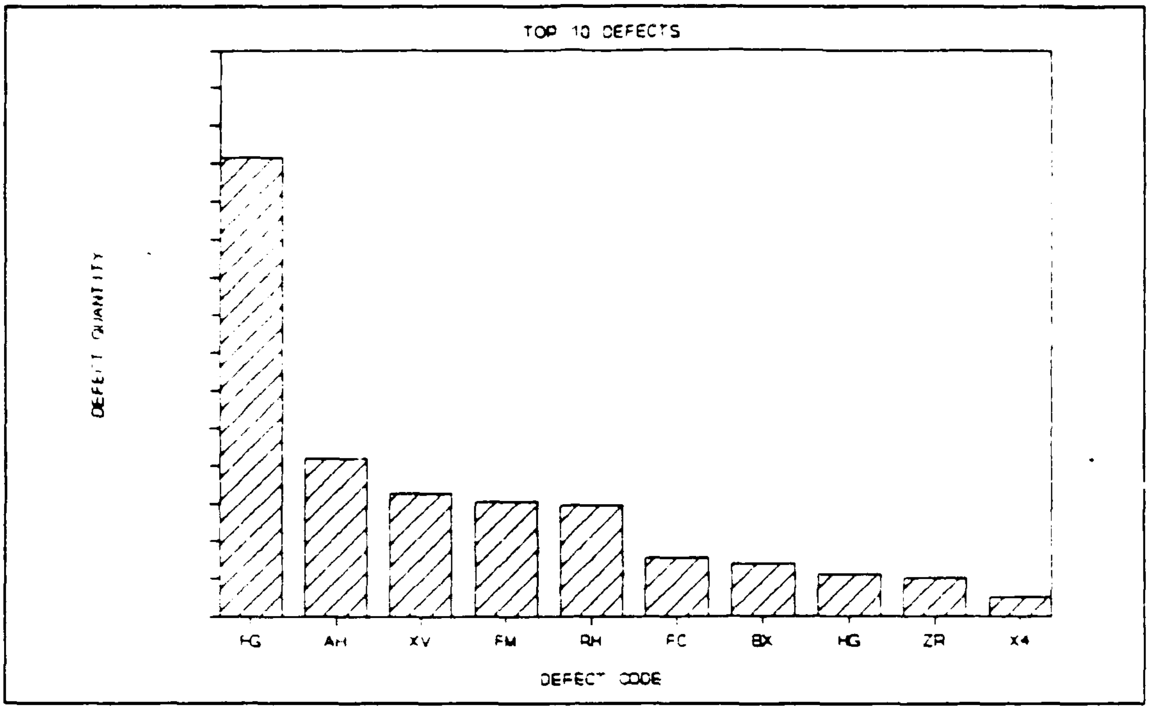

Figure 18. Pareto Analysis of Defect Occurance

Engineering Change Notices. ECNs provide one measure of the number of changes associated with a product. As indicated by Figure 19, ECNs can be due to documentation errors, design errors, or improvement efforts. This information is accumulated at the division level, and is also presented in a tabular format (Table 6). The table identifies the areas of responsibility for ECNs, as well as the reasons for the ECNs.

Customer Return Material. TI/RSD tracks the flow of product returned to them for action (generally for repair). Figure 20 identifies the various stages of flow that customer return material (CRM) follows, and the number

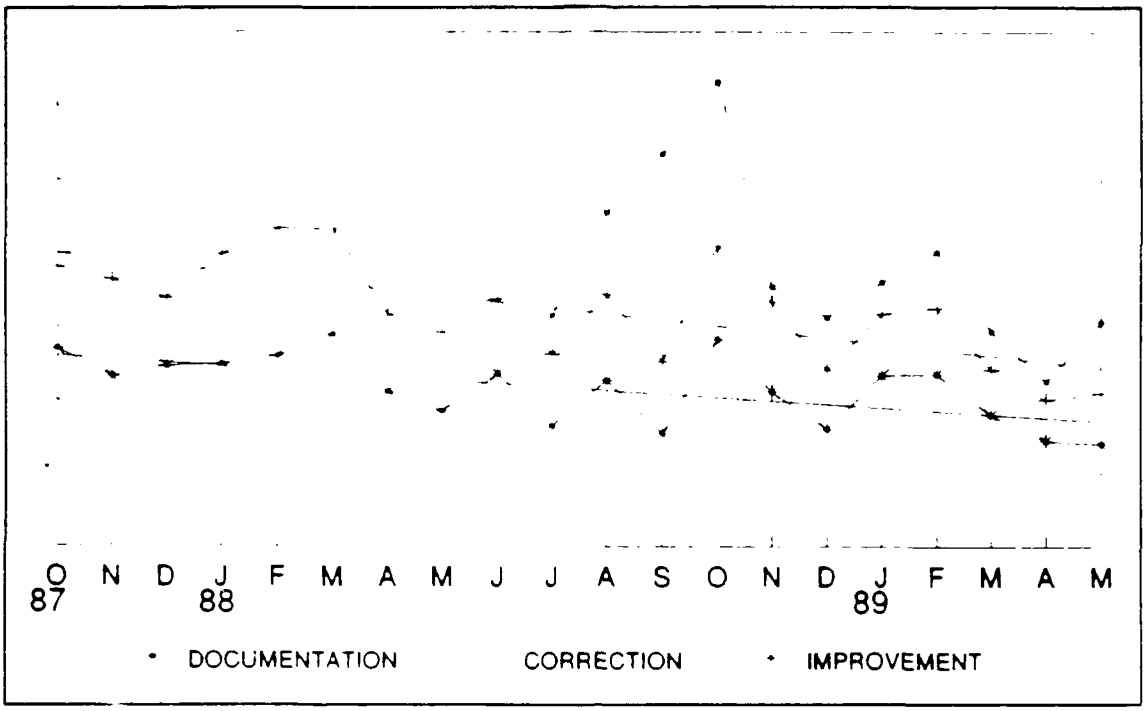

Figure 19. ECN Trends

Table 6. ECN Reason/Responsibility

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
PRIOR ECN												
COMPATIBILITY												
SPEC ERROR												
ENHANCE/PRODUC												
OBSOLESCENCE												
UPGRADE												
DOCUMENTATION												
TOTAL												

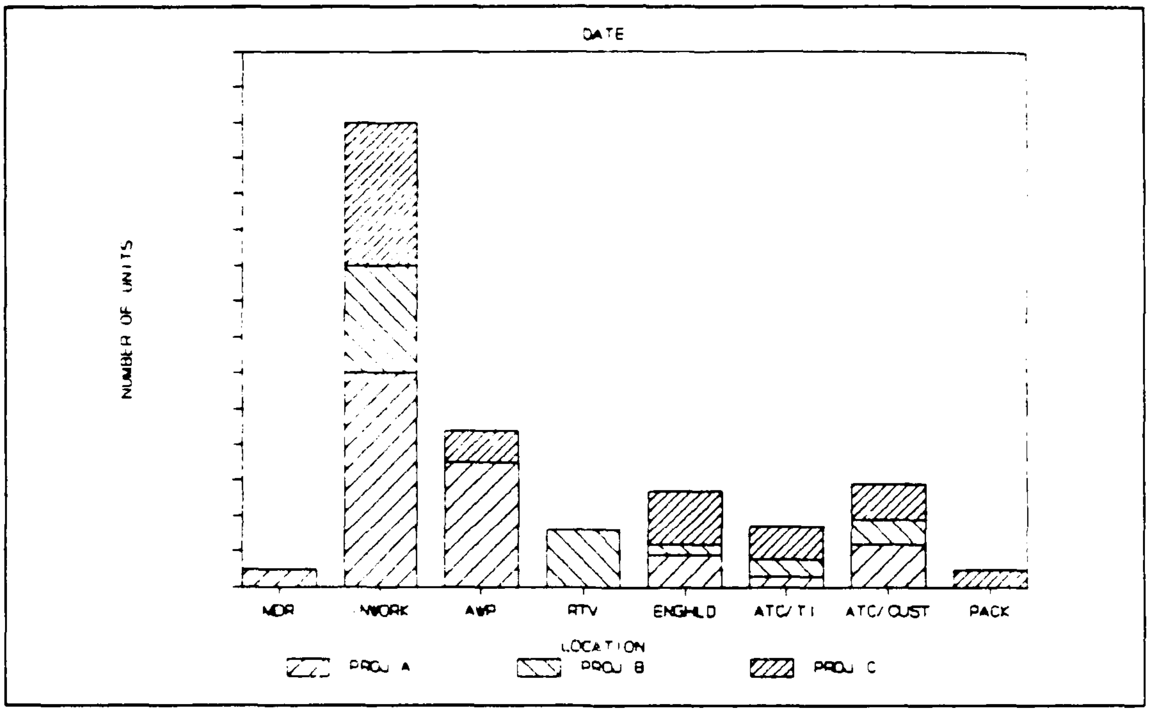

Figure 20. Stages of Customer Return Material Flow

of units a Product Customer Center (PCC) has at each of those stages on a given date. The stages are defined as:

MDR	- Material Deficiency Report
INWORK	- Unit in work
AWP	- Awaiting parts
RTV	- Return to vendor
ENGHLD	- Engineering hold
ATC/TI	- Acceptance test complete/waiting TI action
ATC/CUST	- Acceptance test complete/waiting customer action
PACK	- In packaging for shipment

Figure 21 details the length of time units have been in the CRM flow (used to identify bottlenecks), and Figure 22 shows the turnover and balance of CRM over the past year.

Observations. The quality indicators used on a given program change as the program itself matures from the early

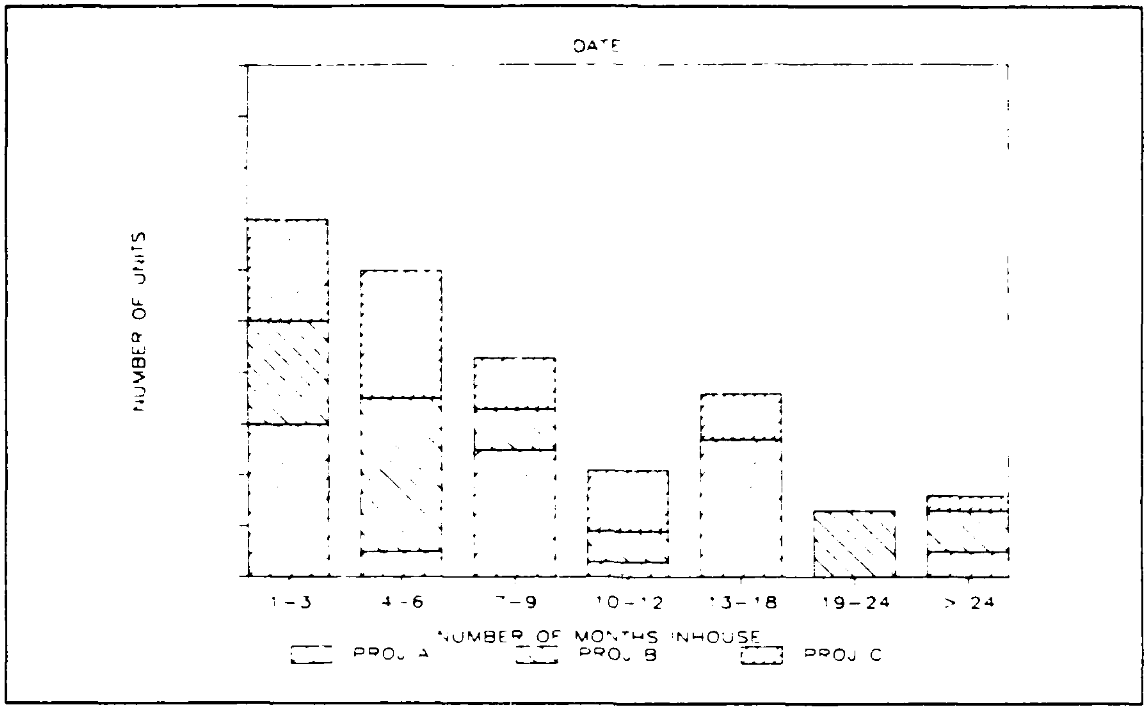

Figure 21. Length of Time in the CRM Flow

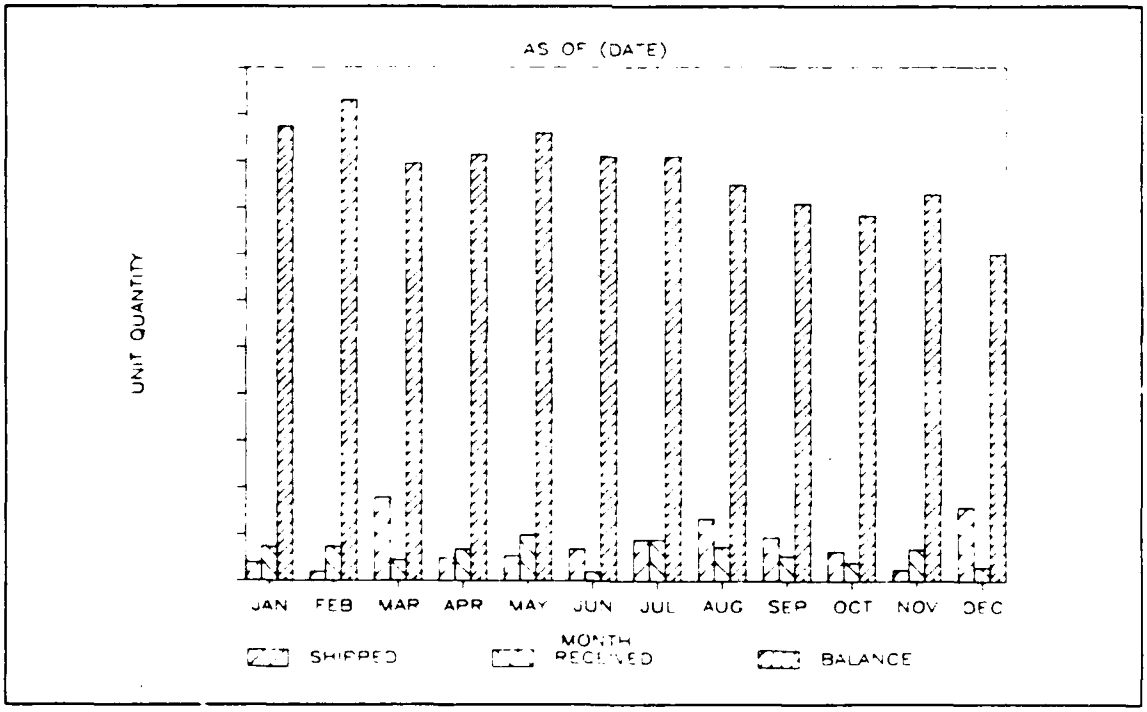

Figure 22. CRM Turnover and Balance

months of production to the final months of the program. As the F-111 program has matured, for example, TI/RSD has shifted focus from test rework to first pass yield to defects per unit. This requirement for having dynamic quality assurance indicators can present a contractual problem: when a contract is definitized several months (often over a year) before production under that contract is started, it is impossible to identify the single set of indicators which would be most appropriate for the duration of that production effort.

Electronic Systems Division (ESD) (25)

Background. ESD is a division of Air Force Systems Command, the agency responsible for acquiring weapon systems for the Air Force. ESD is responsible for developing and acquiring systems such as: long-range, ground-based radars; satellite communications terminals; the Joint Tactical Information Distribution System (JTIDS); the Joint Surveillance Target Attack Radar System (JSTARS); and the Airborne Warning and Control System (AWACS).

ESD defines quality as meeting all contractual requirements. With this definition, ESD does not limit its quality surveillance solely to the requirements of MIL-Q-9858A, but instead charges its personnel with monitoring all aspects of the contract with emphasis on the quality and manufacturing issues. Several of the indicators, refered to as metrics by ESD, will also be of interest to the manufacturing community, and communication will help prevent duplication of effort. Total Quality Management (TQM) fits in well with the ESD philosophy.

Quality Indicators.

Pareto Analysis. ESD uses Pareto analysis extensively for tracking quality problems and progress towards resolving those problems (see Figures 17 and 18 for examples of Pareto analysis). Since the principle behind Pareto charts is that the majority of problems are the result of a few problems, this indicator lends itself well to tracking various defect and yield problems.

Drawings Released. The evolving design progress is tracked to indicate the gap (if any) between the design objective and manufacturing technology and producibility, highlighting any potential schedule problems. Figure 23 shows the actual numbers of drawings released compared to the number scheduled for release, while Figure 24 compares percent actually released to percent scheduled for release. Drawings are tracked by quality personnel since they must be approved by quality prior to release (supporting the TQM philosophy of ESD). Since drawings must be completed before final manufacturing plans and work instructions can be completed, this indicator can reveal early signs of potential problems.

Work Instructions. Work instructions are tracked similarly to drawing releases (i.e., by actual numbers and by percentages). Quality is involved due to the requirement for quality personnel to determine the appropriate inspection points.

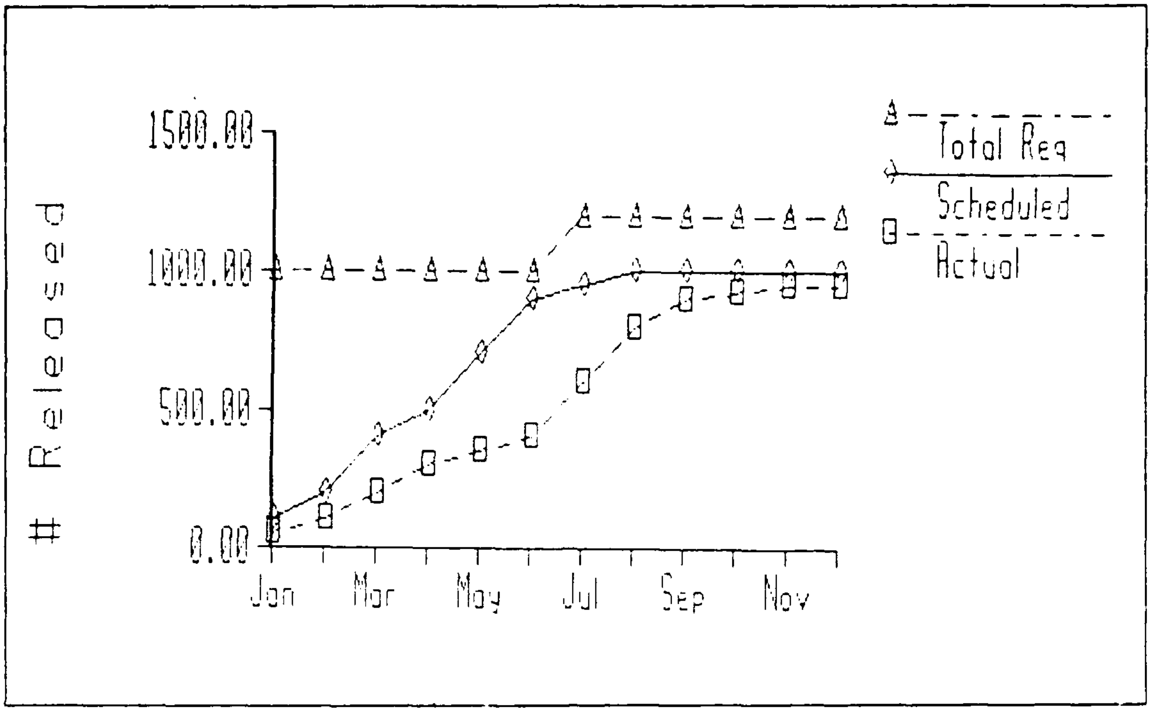

Figure 23. Drawings Released vs. Scheduled

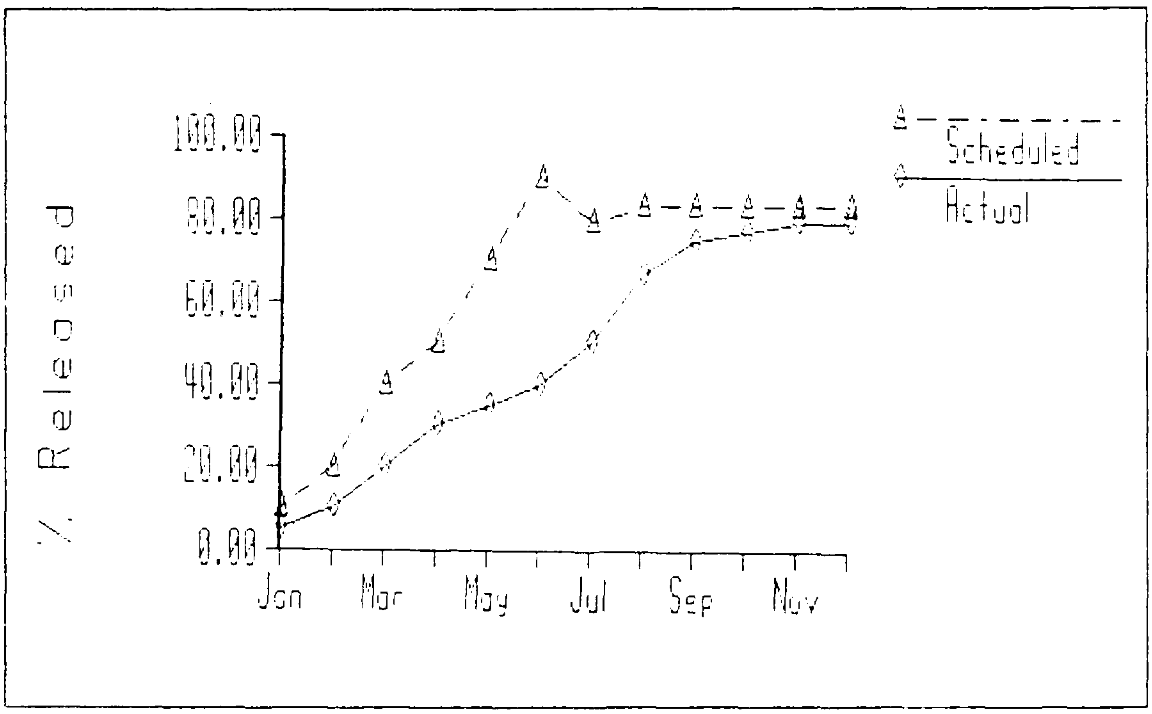

Figure 24. Percent of Drawings Released vs. Scheduled

Purchase Orders (POs). Purchase orders also require input from quality assurance and are tracked to assure all subcontracted items are ordered in a timely manner. POs are tracked using formats similar to Figures 23 and 24. This information verifies that the scheduled number of POs have been issued, but does not verify that the correct items have been ordered.

Material Review Board (MRB). Tracking MRB activity can help identify poor hardware producibility, process deterioration, personnel training needs, and misuse of the minor waiver process. As noted previously, MRB disposition categories include scrap, rework, repair, return to vendor, and use as is. Excessive dispositions in any of these categories can identify management need to control nonconformances. Figure 25 identifies the actual numbers of MRB actions within the facility and in the program of interest, while Figure 26 compares the percentage of MRB actions by the program to the total number of actions.

Scrap, Rework, Repair (SRR). Scrap is usually defined as the cost of material and value-added labor invested in an item no longer usable by the program. Rework is additional value-added labor required to bring an item in conformance with specification (often the result of work instruction steps not accomplished). Repair is additional value-added labor required to bring an item to a condition where it can be used as is (e.g., plugging a misdrilled hole and redrilling the hole in the correct location). Tracking

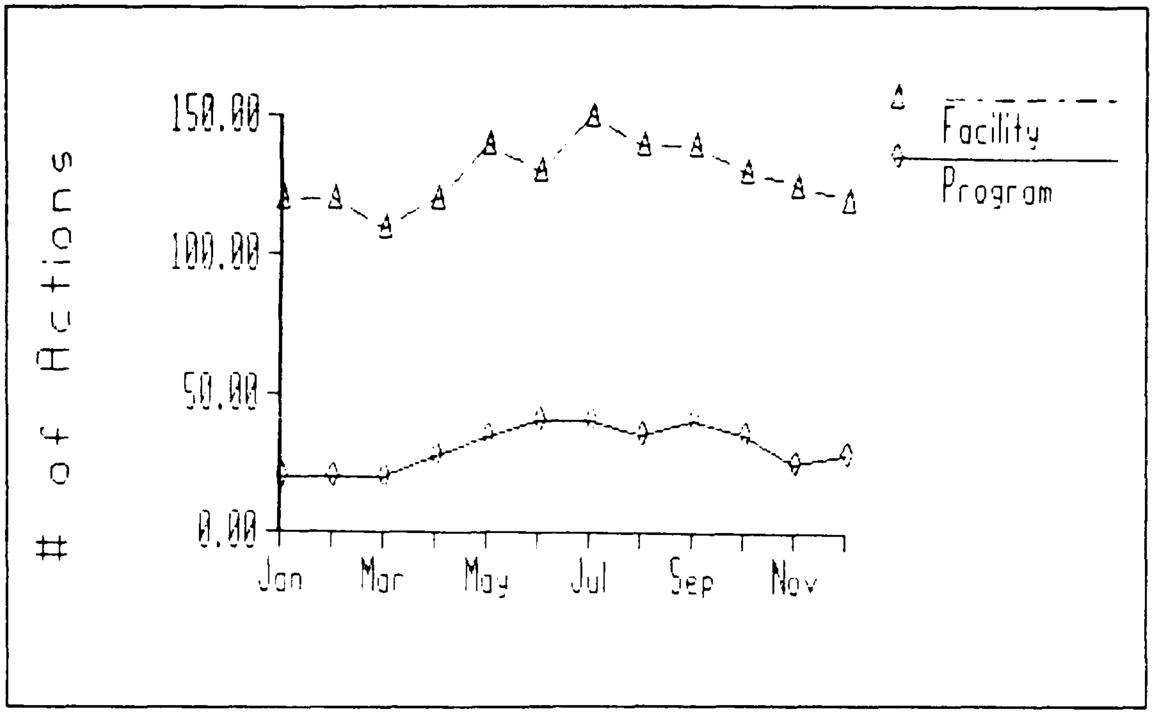

Figure 25. Facility and Program MRB Actions

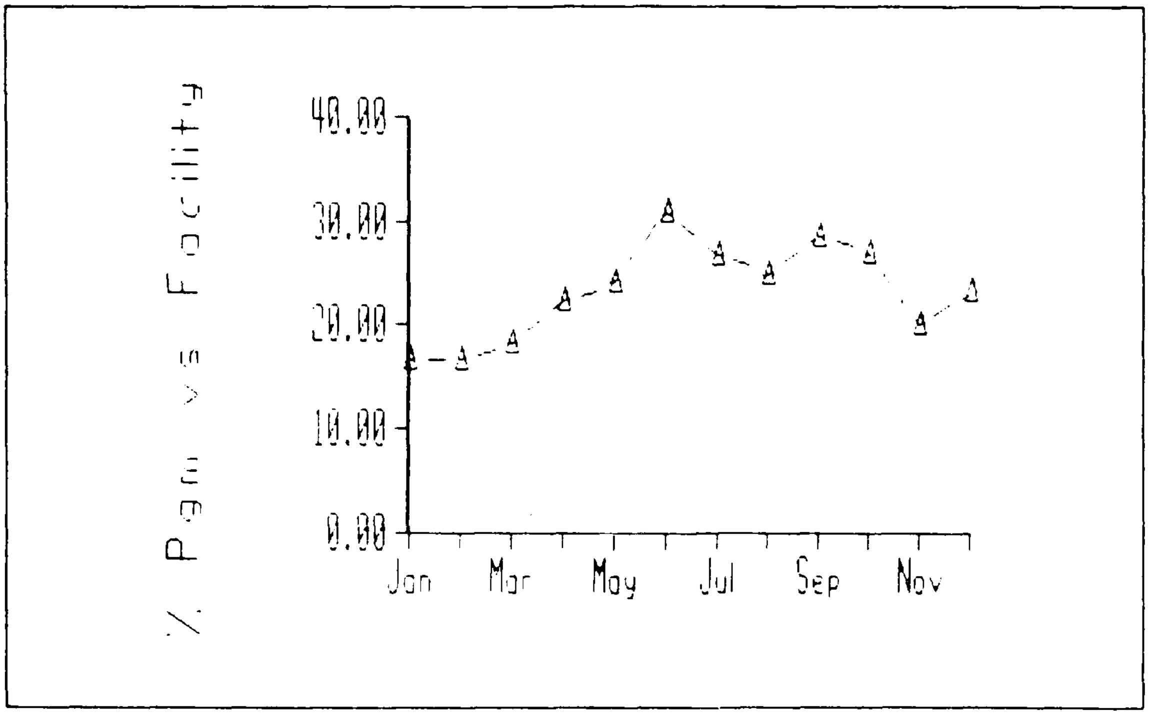

Figure 26. Ratio of Program MRBs to Total MRBs

the amount of SRR within a program can identify process control problems, producibility problems, and the need for modernization and training. Low SRR rates indicate effective quality planning by way of a design that is free from error and one which can be easily produced and controlled. ESD analyzes SRR rates as a percentage of production costs, defined as labor costs. Figure 27 shows actual SRR costs and production costs, while Figure 28 shows SRR as a percentage of production costs.

Yield. ESD monitors yield rates to reveal information on process control, workmanship, the need to improve producibility, and the need for manufacturing technology improvements. Screening at lower assembly levels

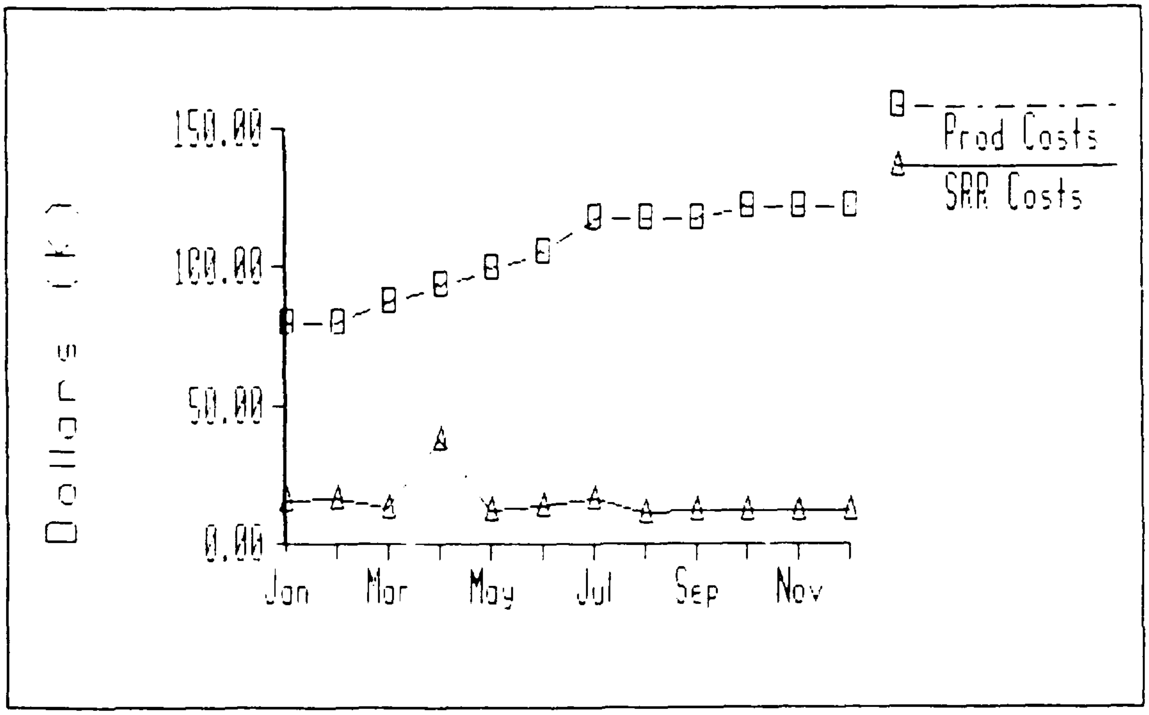

Figure 27. Actual SRR and Production Costs

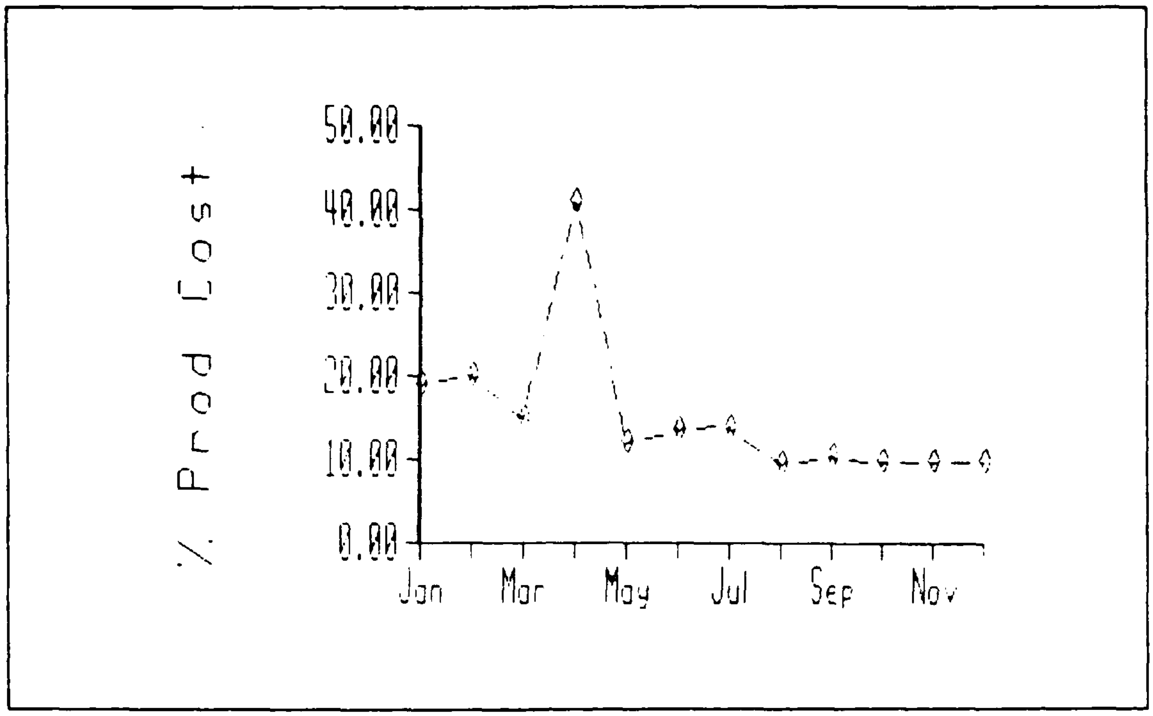

Figure 28. SRR as a Percentage of Production Costs

is suggested as a method for improving the yield at subsequent inspections and tests. While ESD acknowledges the likelihood of low yields for new or special process, quality personnel expect improving trends with process maturity. Yields of 100% are the desired goal where feasible. A general format for yield charts was shown in Figure 12.

Observations. Perfection is a utopia not likely to be achieved during a program. Because of this, mutually agreed to goals must be imposed on appropriate portions of the quality program. These goals should be based on past performance, yet should emphasize continuous improvement. The QAS must realize, however, that additional improvement may not be possible at a given level of technology. When technology becomes the limiting factor, the technology itself must be improved to continue the improvement process.

A good quality system is necessary, but is not enough to insure a high quality product: a contractor with seemingly a good quality system may still produce a poor product. Likewise, evaluating a contractor's quality system is not enough to insure product quality. Visible management commitment is also a necessary ingrediant.

Aeronautical Systems Division (ASD) (2)

Background. ASD is a division of Air Force Systems Command, the agency responsible for acquiring weapon systems for the Air Force. ASD is responsible for developing and acquiring systems such as: the B1-B; the Advanced Technology Bomber (B-2); the Advanced Tactical Fighter; the Short Range Attack Missile II (SRAM II); the F-15 Eagle; the F-16 Fighting Falcon; and the Maverick Missile.

ASD defines quality as conformance to contractual requirements, with the understanding that fitness for use is a m' 'or consideration when making contract-related decisions. With this philosophy, the decision on whether to grant a waiver or deviation is based on the usability of the product in the field, and not solely on whether or not the product meets the contractual requirement. This acceptability criteria allows flexibility in the decision making process.

Indicators. The ASD managers did not present any particular formats that they use to gather information. Instead, they stressed the necessity of following the intent of MIL-Q-9858A over the more specific guidance offered in Handbook H50. The focus of an evaluation should be as stated in the summary section of MIL-Q-9858A (Quality Program Requirements), that the contractor has

> An effective and economical quality program, planned and developed in consonance with the contractor's other administrative and technical programs . . . . (6:1)

An evaluation based on this focus would look at each process and evaluate if it is being done correctly, with breadth of coverage being a major consideration. Each functional group, including engineering, configuration, test, contracts, shipping, and receiving, should have measurable indicators that identify how well they are meeting the needs of the next process.

In addition to evaluating the indicators of each functional organization, the QAS must identify the effectiveness of those indicators. The indicators must be reviewed and acted upon in a timely manner, not merely passed up the coordination chain. Just as Deming disapproves of posters in the workplace taking the place of true management commitment, indicators can not be allowed to become paperwork exercises fulfilling policy requirements. By nature, indicators are only identifiers of problems; the investigation of causes and elimination of those causes is still the major goal of quality imrovement efforts.

Indicators must be used to identify as many of the needs of the customer as practical. An indicator measuring only the turnaround time of a contract modification does not address what may be the more important issues of accuracy and completeness; a modification with a rapid turnaround that is returned because of errors does not meet the needs of the customer. Consequently, the QAS must be prepared to not only determine the breadth of functional coverage and the effectiveness of the indicators used, but must also determine the breadth of coverage within the function.

ASD managers acknowledge the usefulness of the indicators being used at the other locations studied. In particular, cost of qualtiy (COQ) information was noted to be useful when attempting to convince a contractor of the need for quality initiatives in his company. When a manager realizes what portion of his revenue is lost to defects, failures, and inspections, he will be more inclined to implement preventative quality efforts. COQ information is useful both as an attention getting tool and as a means of demonstrating how focusing the quality effort towards defect prevention can be rewarding.

Observations. Beyond the traditional definitions, ASD managers view quality as a management application of the quality discipline. Supporting the Total Quality Management (TQM) ideas, this view recognizes that quality responsibility does not reside solely in the Quality Assurance Department, but is instead a universal management concern. The quality department should act as a catalyst to the quality efforts being achieved throughout the company, assisting with the technical details of the quality effort as needed and providing encouragement to continue when the results of the efforts are slow to materialize.

The concept of viewing the next process as customer is also espoused by ASD managers. This idea requires communication among the functional departments and the program office, each group defining what inputs they require to do their job (providing another group with some sort of input) correctly and efficiently. Considering the next process as customer enables each function to define goals and see how well those goals are being attained. This idea also supports the fitness for use definition given earlier--the needs of the next process should guide the requirements being enforced.

A quality improvement effort is intended to reduce variation in the normal process, allowing more of the work passing through to be within acceptable standards. Through quality improvement, the contractor can ultimately cut costs for both himself and the government. A barrier to quality improvement programs, however, is the structure of the contract: the profit for a contractual effort is commonly tied to the cost of doing that effort. In reducing costs on the current contract, the contractor will ultimately reduce costs on future contracts and his profit on those contracts.

A system of allowing sufficient profit while encouraging cost saving techniques such as quality improvement efforts is required, and experimental contracting efforts are being implemented to study different applications of profit.

V. Results and Analysis

This chapter provides the results and analysis of the study, beginning by addressing the issues raised in the first three chapters. The issues are followed by a discussion about the new Quality Assurance Specialist (QAS) and the situation faced when first entering a system program office. Ideas presented here may assist the QAS in putting his new assignment in the correct perspective. Following this is a presentation of quality program elements that might be found in an "ideal" company. The appropriate quality indicators are discussed here, along with their applications, merits, and shortfalls. Finally, barriers to the quality program are covered, identifying various problem areas both the QAS and the contractor may face while developing an appropriate set of quality assurance indicators.

Issues Raised in Chapters I - III

MIL-Q-9858A. The first issue centers on whether MIL-Q-9858A, Quality Program Requirements, is an outdated document and should be revised, or whether it still contains valid guidance. Discussions during this study revealed that the quality managers believe MIL-Q-9858A is still a valid, useful document. The format of MIL-Q-9858A as general guidance has allowed it to apply equally well now as it did 25 years ago. MIL-Q-9858A does not attempt to support any quality philosophy over another, but instead supports the idea that a good quality program is a necessary ingredient

ingredient in quality product. By not requiring the development and philosophies of that quality program to be identical for each company, MIL-Q-9858A has allowed the companies to tailor programs to meet requirements.

MIL-Q-9858A does, however, require certain central elements to be present in the quality program. These elements are not intended to limit the contractor's program, but instead to provide a foundation on which the contractor's program can be developed. As discussed in Chapter II, additional reading in the Department of Defense publications governing quality programs reveals the expectation of quality programs to support both the conformance to requirements definition of quality as well as the fitness for use definition. Information obtained during this study supports the contractor's intent to comply with this expectation. They have developed their programs starting with the central elements and expanded them to include the fitness for use philosophy. Emphasis on fitness for use is evident in Texas Instrument's (TI) elimination of the need for government-approved material review board decisions, ITT's progress in computer-aided design, and the overall support of "next process as customer."

Although MIL-Q-9858A is not considered to be outdated, the need for more specific guidance is recognized. Both ITT and TI have established policies based on their interpretation of MIL-Q-9858A. These policies guide everyone from management to the floor workers in how their tasks should be performed to comply with requirements, identifying what to do, how to do it, and how often to do it. Although these policies are flexible enough to change with changing technology, they are expected to be rigidly followed while in place.

The government also recognizes the need for specific guidance. Electronic Systems Division (ESD) quality managers have developed a collection of metrics to be used when evaluating contractors, including both manufacturing and quality assurance issues. Aeronautical Systems Division (ASD) quality managers are developing a similar guide for use at ASD. Based on the requirements and intent of MIL-Q-9858A, these guides are intended to supplement the Quality Program Requirements guidance.

Research Questions.

Quality Definition. How is quality defined in the industry? The contractors are paid according to how well they meet contract requirements. If they go over the expected cost, they lose some profit (in firm, fixed-price contracts which are typical for production efforts). They may be penalized financially for missing delivery schedules or for providing products that work in the field but do not meet specification. Because of this, the contractors are required to have a quality definition which supports the conformance to requirements philosophy. This research has found this to be true. In addition, the research has shown that the government also mentions conformance to requirements as their primary philosophy.

Despite the financial bias supporting conformance to requirements, the fitness for use philosophy also played a large part in each of the four location's overall quality philosophy. The fitness for use philosopy was most evident in the broad-based support of considering the next process as the customer and in the concern for meeting minimum standards. As new methods of determining contract profits are developed, the fitness for use quality philosophy will be allowed an even greater influence on the quality program.

Emphasis. Which areas of the contractor's quality program should be emphasized in determining the status of the quality program? The contractors tended to place more emphasis on quality evaluation of the areas that were subject to quantifiable analysis. These tangible areas of the programs were identified in Chapter IV. In this research, neither contractor relied on a single indicator more than any other, realizing the need for a comprehensive quality program. A given area would receive added attention if a problem were to develop in that area, but daily attention was given each area by individuals responsible for the details of that area.

The government, however, focused primarily on the more intangible areas of the contractors' quality programs, especially on the active, visible management commitment to quality. No measures were presented for objectively evaluating this commitment, however. In lieu of being able to provide objective measures of management commitment, the government used the same tangible indicators as the contractors.

Current Indicators. What quality indicators are currently being used by both the industry and the government? The indicators outlined in Chapter IV and discussed below as being used by the "ideal" quality program are the quality indicators currently being used by ITT, TI, ESD, and ASD. Although the individual indicators are not used universally, all focus on the tangible areas of the quality program. Indicators in use either identify areas where additional attention is necessary immediately to solve a problem (e.g., yields and defects) or areas where potential problems exist (e.g., statistical process control (SPC) and drawing release summaries).

The indicators currently used also focus on the conformance to specification apects of the quality program, that is, they identify areas where the product may not meet standard. As focus shifts more towards fitness for use or customer satisfaction, the indicators may shift more towards monitoring the non-hardware processes within the company.

Information Basis. What information is used as a basis for each indicator? As indicated by the format examples presented in Chapter IV, and as dictated by the nature of the tangible indicators, the quality indicators are based primarily on hardware-process data, including the drawings, vendors, and purchase orders supporting the production of the hardware.

The specific basis for each indicator can be found in the sections describing the indicator.

Indicator Usage. Who uses each indicator, and why? With the exception of the cost of quality (COQ) indicators and the pedigree charts, each indicator is used by the quality assurance manager responsible for monitoring and controlling the quality of the production line. The information is accumulated on a daily, weekly, or monthly basis to identify either current problems or potential problems. The fact that an indicator is not used on a daily basis does not negate its importance. Customer-returned material, for example, typically does not accumulate rapidly enough to make daily information feasible or useful. The frequency of use will depend on the aspect of the quality program the indicator is intended to monitor.

The COQ and pedigree indicators are used to keep upper management abreast of the status of two portions of the quality program. The time required to obtain COQ information (often four to six weeks) and the long-term nature of the pedigree information make these two measures almost useless as shop floor management tools. They are more suited as tools upper management might use to evaluate the efforts of the quality managers themselves.

Unused Indicators. What indicators are not currently being used by the Air Force that may provide a better assessment of the quality status of the contractor? This research did not identify any indicators used by the industry but not used in at least a similar format by the government. Since the contractor interviews were both performed before the government interviews, the indicators used by industry were discussed with the government managers. The government managers were familiar with each of the indicators used by the contractors, but did not necessarily monitor each of those areas on a frequent basis. Vendor ratings for subcontractors, for example, were not evaluated regularly unless a problem arose in that area. The contractor, however, felt it necessary to monitor the quality of his incoming material frequently. The fact that the government managers might not be using an indicator on a regular basis was not identified by either side to be a deficiency in government monitoring.

The New Quality Assurance Specialist (QAS)

The newly assigned QAS is at a disadvantage upon first entering the system program office: his peers are more experienced and his supervisor expects a rapid learning curve. The first part of this section will offer a way to deal with the problems of the learning curve, and explain a use for the information provided by this study. Following will be a discussion on what the focus of quality indicators should be. Finally, before describing elements of an "ideal" quality program, the need for flexibility in the QAS's use of quality indicators will be addressed.

QAS Education and Training. The new Quality Assurance Specialist (QAS) has guidance available from superiors, peers, organizational operating instructions, MIL-Q-9858A, and Handbook H50, along with the countless publications on quality, manufacturing, engineering, configuration, contracts, and other functional organizations. These sources are not all published by the Department of Defense and are available from the Government Printing Office, libraries, and bookstores. From these abundant sources of knowledge, however, the QAS must be able to distill the information most useful in accomplishing the new job.

Compounding the problem of overwhelming information is the expectation that the QAS can "pick up" the knowledge on the job. Rarely is the QAS given any formal education in the general area of quality assurance which might simplify the search for appropriate guidance. Instead, the QAS is given on-the-job training, typically under the "fire fighting" atmosphere of daily systems program office activity. This type of education focuses more on problem solving than on problem prevention. This initial experience can bias the QAS towards expecting quality programs to emphasize defect detection more than prevention.

Insufficient formal education coupled with biased on-the-job training results in QASs who are uncertain about the nature of their job. Given sufficient time, the QAS will receive the necessary formal education and garner information from the various publications. How more time than should be necessary will be spent in this education process, during which the QAS will be performing below his or her potential.

Understanding that the current on-the-job training of QASs is not the ideal situation, this study attempts to provide a basic review of certain quality assurance indicators currently used in the defense electronics industry. The reader will be able to review the indicators and observations presented in this study for applicability to his program. The indicators are being used by defense electronics companies with excellent quality programs and by the government offices monitoring those contractors. The indicators presented should provide a foundation while not limiting innovative quality progress by either the QAS or the contractor.

QAS Focus. This study focused primarily on tangible quality assurance indicators, due more to the relative ease of maintaining these indicators than to the relative importance of tangible indicators over "intangible" indicators. In fact, the QAS should focus on the entire quality program, not just the hardware related areas. The Total Quality Management philosophy instilled in the quality programs of each location studied supports quality being a part of each individual and each process, and ESD reminds the reader that a good quality system alone does not guarantee a quality product. ASD concurs with this view by suggesting that the quality program meet three goals: breadth of quality commitment throughout the company, breadth of quality commitment within each organization, and effectiveness of the quality commitment within each organization. Posters, slogans, and indicators are not a substitute for quality commitment.

The QAS must realize that even within the same company the typical product line is independent in many respects from the other product lines. Because of this separation, the types of indicators used and the quality philosophy followed may vary from one product line to the next. The differences in quality management are likely to be considerably greater between companies. Differing philosophies and varying indicators make comparisons with other companies or product lines virtually impossible. Focusing on a single program and the improvements that can be made to the quality efforts of that program helps foster an attitude of cooperation from the contractor.

Flexibility. The QAS should review the quality indicators and observations presented here in light of his quality program. Some indicators may be applicable, others not. As indicated by Texas Instruments, the QAS must be flexible when choosing quality indicators to apply to a program. As a program matures from the early stages of production to the last months of the production run, the relative importance of the program's indicators will change accordingly. The need for good communication between the contractor and the government QAS is evident. The experience of the contractor will prove invaluable when attempting to define the indicators that will be required by a contract whose effort will not begin for several months, even a year.

As noted above, different companies and programs use a variety of quality indicators. Although some of these differences are due to the management style of the contractor, other differences may be due to differing data analysis capabilities of the programs. While one program may employ extensive automation in data collection and analysis, allowing rapid output of a variety of reports, another program may rely on manual collection and analysis of data. It would be unrealistic to expect the two programs to be equally receptive to innovation. The QAS must be flexible not only to different management philosophies and indicators, but also to the physical limitations of individual programs.

The "Ideal" Quality Program

This study has identified several key areas of a contractor's quality program based on the excellent quality programs at ITT and Texas Instruments and supplemented with information from ESD and ASD. This section identifies those key elements, beginning with the quality management at the contractor. Following this will be a discussion of the program areas where quality indicators play a role, and a review of the importance of quality indicator visibility. Automation as an aid to the quality program will be covered next, followed by a discussion focused on continuous improvement. This section concludes with a review of the changing trend in philosophies from the current idea of conformance to requirements to the emerging considerations of fitness for use.

Quality Management. Management should be at the heart of the quality efforts within the company. Handbook H50 discusses

> An effective and economical quality program, planned and developed in consonance with the contractor's other administrative and technical programs . . . . (6:1)

In addition, MIL-Q-9858A describes the quality program as assuring ". . . adequate controls throughout all areas of contract performance; e.g., development, manufacturing, and shipping" (4:3). Clearly quality responsibility lies with the company's management and not solely with the manager of the quality assurance department. A program that is integrated with the other programs within a company must be backed by a center of authority and responsibility; a program without management support will falter.

Although the QAS may find it difficult to measure actual management commitment and involvement, indications should be evident. The quality assurance function should be at the same organization level as manufacturing and engineering, for example. A quality function reporting to the manufacturing manager runs the risk of being placed second, behind manufacturing and schedule concerns. The receptiveness of the other functional organizations to quality initiatives is another indication that upper management places a priority on quality. The order of appearance of the quality function and the time alloted to their report at the weekly and monthly program meetings, and the periodic company meetings, is a manifestation of management commitment. Putting quality last on the list at meetings, when everyone is anxious to get back to work, may indicate quality's true priority at the company.

The requirement for upper management commitment does not preclude the necessity of having a quality assurance department. This department must be available to aid management in the implementation of their commitment. Proper education and training are required to insure harmony of the quality program with the other programs at the company, as well as to monitor the effectiveness of the quality program. Engineering, configuration, and contracts management, not skilled in the development of quality indicators, must be aided. The quality department also serves as a focal point for interfacing with the government QAS.

Having the quality program be in harmony with the other "administrative and technical programs" implies a breadth of coverage to include all functions within the contractor's facility, and an integration of programs that fosters communication. Considering the next process as the customer simplifies the definition of requirements: anybody receiving information from an organization is defined as that organization's customer, and their requirements must be considered when sending them information. This requires an understanding of the needs of the other functional organizations and a willingness to integrate systems and programs.

The next process is not limited to organizations, however, but includes the floor worker and the subcontractors as well. The quality program must consider these needs as well as the needs of the funtions. The floor worker requires unambiguous work instructions, the proper tools, and satisfactory working conditions to do the job properly. These requirements make them the customers of the production engineers, the calibration department, and the maintenance department. The subcontractor requires the flowdown of quality requirements, the detailed design, and the packaging needs. These requirements make them the customers of the quality department, the design engineers, and the receiving department. Realizing that the "customer" can be anyone encourages the flow of the quality program throughout the company.

Quality Indicators. Formats for several quality indicators were presented in Chapter IV accompanied by a limited discussion concerning each indicator. This section will review these indicators by discussing the merits and shortfalls of each indicator.

Defect / Yield. Defect and yield charts usually constitute the largest portion of the tangible indicators tracked by a company due mostly to the wide applicability of this category. Defects are usually based on inspection results and can apply to all stages of the production effort including receiving, in-house component manufacture, assembly, solder, and final visual inspection. Yields are typically based on test results including incoming, printed wiring board test (bare and populated), and line replaceable unit (LRU) under a variety of conditions from ambient to freezing to excessive heat.

Defect and yield charts are of most use to the first-level quality managers who can effect immediate changes or studies based on the results of data analysis. Data collection and analysis must be timely for these indicators to be useful, supporting the need for automated data collection and analysis. Summary charts such as the Pedigree charts used by Texas Instruments (Figures 15 and 16) are useful as an informative tool to keep upper management aware of the current defect or yield trends, while trend charts are valuable tools for informing the quality manager of the effects of specific corrective action programs (Figures 13 and 14) and long-term quality improvement efforts (Figure 12).

The generalized yield chart (Table 5), affectionately known as a "seeing-eye chart" by the quality manager, is a busy chart potentially containing a great deal of information. A review of this chart will identify those items with the lowest yields and those processes with the lowest yields, allowing the quality manager to direct his attention to those areas. The total yield column is the product of the yields at each point through which an item passes. As is true with reliability figures, the value of the total yield column is dependent on the number of yield points used in the calculation (e.g., $0.9 \times 0.9 = 0.81$ while $0.9 \times 0.9 \times 0.9 = 0.729$). If the total yield column is given unnecessary emphasis, especially be the QAS, the quality manager's incentive to remove a point or two from the chart would be great. The reader must keep in mind that the purpose of indicators from both the contractor's and government's point of view is the same: identify those areas needing the most attention. This goal can be achieved with this chart by emphasizing the proper areas.

Cost of Quality. Cost of quality information, including scrap, rework, and repair (SRR), was indentified by ASD as being of greatest use when dealing with contractors who are reluctant to initiate quality improvement efforts. Highlighting to a manager the amount of money essentially thrown out the window can produce dramatic results. At the conscientious quality manager's level, however, cost of quality information is not as useful. If the quality manager has active efforts in reducing and preventing defects, raising yields, and narrowing process deviations, the cost of quality will decline accordingly. The charts can, however, identify the areas requiring the greatest attention and the cost trends in various areas (Figures 2 - 6, Tables 2 - 3).

Cost data is among the most proprietary data easily available to the QAS and will be the first information withheld if the contractor determines that the information is being used for comparison to other programs. Due to the different auditing systems and cost classifications, it is not possible to compare cost data across programs or companies. The information should be used only for problem identification and trending purposes within the program.

Because cost data are used only within a given program, the data base used to support the indicator is not of great importance as long as the data include all major contributors to the costs being identified. Displaying information as a percentage or ratio (Figures 2, 4, 6, 8, 10, and 28) takes into account the varying level of activity for a given period, while displaying absolute values (Figures 3, 5, 7, 9, and 11; Tables 3 and 4) identifies those areas accounting for the largest share of the costs. Tables and charts presenting information based on both absolute values and ratios (Figure 27 and Table 2) combine the benefits of the previous formats.

Process Control. The theory supporting use of process control is based on the contention that by carefully controlling the process one will be controlling the quality of the result. Process control therefore lends itself to preventative actions as opposed to the corrective reactions inherent in inspection, and is applicable to processes measuring either attributes such as pass/fail or discrete values such as weight or length. Although a description of process control is beyond the scope of this study, more thorough discussions are available (8).

The nature of process control charts dictates that they be used by the managers and operators closest to the process. An unfavorable trend identified by the control chart needs to be corrected immediately and not after it has been discussed at the weekly meeting. Consequently, the QAS will not likely monitor the control charts themselves so much as he will monitor the effective use of the flow charts by the contractor.

Pareto Analysis. Quality managers are very aware of the tendancy for 80% of the problems to be caused by 20% of the parts, giving rise to the use of Pareto analyses (Figures 17 and 18) as quality indicators. Especially useful on defect analysis, Pareto charts can identify either the parts with the highest defect rates or the defects with the highest rate of occurance. These charts do not take into account the fluctuating level of activity that may influence the number of defects detected.

Vendors. Vendor rating systems are valuable tools for monitoring the quality of those subcontractors supplying parts for use in the contractor's product. The vendor rating system discussed in this study is based primarily on the rejection rate of the supplier's product. However, automatic rating downgrades are possible if the vendor fails to respond adequately to corrective action requests or fails to pass a quality survey. An additional criteria could be to include vendor reliability by factoring early or late deliveries into the rating formula (early deliveries may not be desirable if the contractor has no place to store the shipment until it is needed).

The indicators presented in this study (Figure 1 and Table 1) are primarily useful for informing upper management of the vendor rating status. The ratings of individual vendors are used by the quality department in determining where to focus their attention. Note that "C" rated vendors may be sole suppliers of critical parts and termination of future contracts with those vendors may not be an option. In these cases the quality department must work closely with the vendors to improve their reliability.

Material Review Board. Monitoring material review board (MRB) actions will give the QAS an indication of the amount of nonconforming material being produced or received. Whether the company allows use-as-is or nonstandard repair procedures or not, any MRB disposition (standard repair, scrap, rework, or return to vendor) is the result of nonconforming material. Comparison charts such as those used by ESD (Figures 25 and 26) are useful in determining whether the program of interest is having more problems than company in general.

A product requiring an MRB disposition is the result of a process deviation. Perhaps more important than the absolute or relative number of MRB dispositions is the effectiveness of the corrective actions implemented to prevent reoccurrence of the problems.

Engineering Change Notices. Engineering change notices (ECNs) are generated as a result of change within the program. Considerable change might be expected early in a program while design efforts are being finalized, but stability is expected as the program matures. The cost of ECNs can be presented as discussed earlier, while the trend in the number of ECNs generated can also be evaluated

(Figure 19). The causes of and functions responsible for ECNs can be identified to indicate areas where additional attention may be required (Table 6).

Customer Returns. The using command will often be interested in the status of customer returns, defined here to be the end user's returns of product that has failed in the field. A chart identifying the number of units at each stage (Figure 20) will identify bottlenecks to be dealt with while a status chart (Figure 21) will identify the results of bottleneck-clearing efforts.

Others. The remaining indicators identified in this study (design, drawing releases, work instructions, and purchase order releases) are additional areas the QAS should monitor. These areas as discussed can provide signs of impending quality trouble but are likely to be of greater interest to the manufacturing managers. An understanding of the requirement to include quality in all facets of the company will encourage the QAS to stay aware of the status of all areas of the company.

Visibility of Indicators. Having visible indicators does not necessarily mean posting the results of test yields or inspections on the work floor. Although this is not necessarily a bad idea, this practice might better be described as the display of indicators and may or may not be supported by the management's quality philosophy. Visibility of indicators more accurately refers to the attention the indicators receive by management. The quality indicators identified above are generally designed for use by the quality department directly responsible for monitoring the program. Decisions can be made at that level concerning the daily operations based on the information presented. Upper management, both contractor and government, must be kept abreast of the quality issues, however. This attention enforces the management's commitment to quality and may be giving the quality manager the authority to make the necessary decisions. Although certain formats may not be suitable for upper management due to the level of detail (see Table 5), summary charts accompanied by explanations for any deviation (up or down) are necessary.

Automation. The installation of computer systems within the quality system can significantly improve the effectiveness of the program. Three areas lend themselves well to automation: processes, test and inspection, and data collection.

Many production processes in the defense electronics industry can benefit from automation. The automated systems are inherently more reliable once the process has been refined to meet the needs of the program, consistantly producing products within a narrow tolerance band. Examples include: processes requiring high degrees of accuracy such as bonding fine wires between hybrid circuits and the circuit board, high volume processes such as the soldering of components to the circuit board, and repetitive processes such as inserting simple components (e.g., integrated circuits, resisters, capacitors, and diodes) on the circuit board. Automation of processes such as these also invites the application of statistical process control.

The complexity of the products in the defense electronics industry in many cases dictates the necessity of automated test and inspection. Circuit boards with hundreds of potential electrical paths are assembled into line replaceable units (LRUs) with thousands of potential electrical paths. These LRUs must be evaluated and stressed to insure survivability in the final weapon system, a formidable task if required to be performed manually. In-circuit testers that verify the electrical integrity of the LRU and environmental test chambers that operate LRUs at simulated environmental extremes are two examples of automated test equipment commonly used.

Just as automated processes can reduce the standard deviation of precision processes, inspection can help insure timely detection of products that do not conform. Coordinate measuring machines can confirm the alignment of critical components, wire-pullers can verify the bond strength of fine wires, and cameras can detect the absence or misalignment of components on a circuit board.

Automated data collection and analysis can dramatically reduce the time necessary to determine the existance of a current or potential problem. By making indicators more "real time," fewer defective items will pass before the problem is noted, allowing the indicators to be used as preventative tools rather than reactive tools. Automation of manual data collection is relatively simple--have the deficiencies entered into a computerized data base rather than onto a piece of paper. Automated test and inspection operations also enter anomolies into the data base automatically. In addition, an automated data collection and analysis system can enhance the flexibility and usefulness of the information reporting system.

Continuous Improvement. The basis for Total Quality Management is continuous improvement in all aspects of all processes. This idea can easily be applied to the aspects of the contractor's quality program, but must be applied critically. In areas where much improvement is possible (based on the experiences of both the QAS and the contractor) a continuous improvement goal might not provide the incentive necessary to achieve those large gains. In this case, continuous improvement would imply that a little improvement this year and a little improvement next year is acceptable, even when great improvement is expected. In a situation where improvement has shown to be slow and difficult, again based on the joint experiences, continuous improvement might be an acceptable goal, implying that any improvement is a good trend.

The QAS should be aware that continuous improvement may be a utopia, as suggested by ESD. Improvement may be limited by the physical technology of the process (e.g., a wave solder machine or a calibration device) or by the current "intellectual technology." The latter refers to the design of experiments to improve the process. Taguchi's method for bringing a process to its peak can reduce the number of experimental runs necessary to "tune" a process from hundreds to a dozen (21:65-71). This advance in intellectual technology breathed new life into the improvement of many physical processes.

The QAS and the contractor should mutually consider the expectations and technical capabilities of a process in light of the current intellectual technologies and set realistic goals for that process.

Changing Philosophies. Traditional views of the customer are as the user of the final product. In the defense electronics industry, this is defined as the airman or soldier using the end item. This definition proved difficult to work with due to the customer often being thousands of miles from the contractor. Feedback about the usefulness of the product was filtered through several layers of command before reaching the manufacturer, forcing at least a delay in production modifications and at worst a requirement for field retrofit. Consequently, the traditional contractor has developed his quality programs around the idea of conformance to requirements. Since the customer was not easily accessible, the specifications were used as a substitute.

This study has discussed the shift in philosophy away from conformance to requirements and towards fitness for use. This shift has been made possible and beneficial by the redefinition of customer from "end user only" to "next process," keeping in mind the possibility that a product satisfying the next process may not satisfy the ultimate "end user." While a fitness for use philosophy does not disregard the contract requirements, it does require the additional consideration of requirements not found in the specification or company policy. The result of these additional considerations may be the revision of policy, but more importantly, is the completion of a job the right way the first time. The end user is not forgotten in the revised philosophy, however, supporting the need for monitoring customer returns.

Barriers

The discussions in the previous section centered on what an "ideal" quality program might include. There are, however, two major barriers to developing an ideal quality program: financial and technological. The discussion of financial barriers will focus on the profit structure of the typical production contract, while the review of technological barriers will center on short production runs, complex products, and the gray areas of inspection.

Financial Barriers. Proponents of preventative quality assurance insist that quality is free, meaning that any money spent on quality assurance can repay the contractor fully in the improved quality of the product and reduced production costs. This idea does not consider the contractual implications of cost reduction. The profit on firm, fixed-price contracts typically used for production efforts has been traditionally computed as a percentage of the contract cost. Any cost reductions during the performance of that contract benefits the contractor directly in the form of higher profits. Contracts for additional buys of the same product will benefit the government in the form of reduced cost (due to the process cost reductions) but lower the profit available to the contractor. As more quality improvements are made, the contractor's profit declines, a system that does not provide the proper incentive for the contractor to investigate cost reduction techniques.

This barrier has been recognized and experimental contracting efforts are being implemented to study different applications of profit.

Technological Barriers. Technological barriers to implementing an ideal quality program also confront the contractor. Among these are short production runs, product complexity, and the gray areas inherent in inspection.

Fiscal constraints limit the number of systems procured. Total production runs can be in the single digits for satelite systems or as many as several hundred for aircraft "black boxes." Large buys are often broken into smaller lots due to the uncertainty of government funding. These short production runs and uncertainty of future lots limit the ability of the contractor to develop a truly mature program. Breaks in the production line impact the learning curve, while periods of low production inhibit the collection of data for trend analysis.

Compounding the problem caused by short production runs is the complexity of the hardware being produced. Production difficulties on simple products can be detected and resolved after the production of only a few items; detecting, resolving, and preventing inconsistent problems on complex LRUs is a much more involved process requiring extensive data analysis. Production processes involving complex hardware are slow to mature, resulting in a slowly maturing quality program (when viewing a mature quality program as being more preventative than reactionary).

Gray areas of inspection, discussed in the section covering ITT's observations, are the third area hindering development of an ideal quality program. Two inspectors having different views on the acceptability of a "defect" may categorize that defect accordingly, causing the occurance of that defect to appear intermitant. Intermitant problems are difficult to analyze, resolve, and prevent, again resulting in a slowly maturing quality program.

Summary

This chapter has discussed the findings and observations obtained during the study. The issues raised in the early chapters have been reviewed, and some of the problems facing the new Quality Assurance Specialist have been addressed. Elements that an "ideal" quality program might contain have been identified, including the necessity of proper quality management, examples of quality indicators and need for visibility, the applications of automation, the issues involved with continuous improvement, the shift in quality philosophy, and the barriers to the development of an ideal quality program. Solutions to some of the issues raised are beyond the scope of this study, but they are mentioned as information for the QAS.

The QAS is should to review the information contained in this study and apply the indicators and ideas judiciously to his program, remembering that quality innovation has resulted in many of the indicators presented.

VI. Recommendations for Further Study

This thesis reviewed quality indicators and observations from the defense electronics industry and the government agencies working with that industry. The results were presented in the form of discussions focusing on indicators to be used by the new Quality Assurance Specialist in developing a set of indicators for monitoring a contractor's quality program. Several recommendations are offered for continuing this study.

A limited population was chosen for this study due to time and fiscal constraints. Although the two contractors studied have excellent quality programs, they still result in only two data points. On the government side, quality managers in staff positions were interviewed resulting in more philosophical views of quality than might be presented by an experienced QAS still interfacing with contractors and monitoring quality indicators. Further study should include additional contractors and government quality assurance specialists still "in the trenches."

This study focused on the quality indicators used primarily by the managers within the quality department itself. Considerable emphasis, however, was placed on the necessity of a comprehensive, integrated quality effort throughout the company. Future studies could evaluate the quality indicators used within other functional offices.

The quality indicators identified in this study were tangible indicators. Tangible indicators present the advantage of being relatively easy to define, measure, and report. They do not, however, encompass the entire quality program, excluding such elements as quality improvement programs and management commitment. An additional study could be accomplished focusing on ways to measure and report these intangible elements.

Although quality assurance indicators used in the defense electronics industry were identified in this study, giving the QAS some tools for use in his "toolbox" of quality indicators, no direct attempt was made to suggest methods of improving the current situation faced by the new QAS. Further study into this area could include the development of a QAS education and training model that would identify the required courses, training, and professional reading lists beneficial to the development of a well-rounded QAS.

Finally, future studies could focus on the technical development of the QAS. The QAS is not a technical expert when first entering this field and needs to know not only what to look for (such as the indicators identified in this study), but also how to use that information. Examples of specific indicators could be presented showing how to identify good and bad situations or trends.

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[redacted]

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GSM/LSM/89S-12	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION School of Systems and Logistics	6b. OFFICE SYMBOL *(If applicable)* AFIT/LSM
7a. NAME OF MONITORING ORGANIZATION	
6c. ADDRESS *(City, State, and ZIP Code)* Air Force Institute of Technology (AU) Wright-Patterson AFB, OH 45433-6583	7b. ADDRESS *(City, State, and ZIP Code)*
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL *(If applicable)*
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c. ADDRESS *(City, State, and ZIP Code)*	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*
A GUIDE TO QUALITY ASSURANCE INDICATORS FOR THE DEFENSE ELECTRONICS INDUSTRY

12. PERSONAL AUTHOR(S)
Ronald A. Goertz, B.S., Capt, USAF

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Year, Month, Day)*	15. PAGE COUNT
MS Thesis	FROM ______ TO ______	1989 September	113

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP
05	01	

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Measurement Quality Assurance
Indicator Electrical Industry
Metric

19 ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Thesis Advisor: Lt Col Richard I. Moore
Assistant Professor of Logistics Management
Department of Logistics Management

Approved for public release: IAW AFR 190-1.

LARRY W. EMMELHAINZ, Lt Col, USAF 14 Oct 89
Director of Research and Consultation
Air Force Institute of Technology (AU)
Wright-Patterson AFB OH 45433-6583

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Richard I Moore, Assistant Professor	22b. TELEPHONE *(Include Area Code)* (513) 255-4149 — 22c. OFFICE SYMBOL AFIT/LSM

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

The purpose of this study was to provide the inexperienced quality assurance specialist (QAS) with a guide to quality assurance indicators for use when working with contractors in the defense electronics industry. The quality indicators used by two defense industry contractors (ITT and Texas Instruments) with excellent quality programs were studied, as were the indicators used by two of the AFSC product divisions (ESD and ASD) that interface with the defense electronics industry.

This research focused on the elements of a MIL-Q-9858A quality program required for the complex systems produced by the contractors studied. Quality indicators and observations about quality programs were discussed, presenting the uses, merits, and shortfalls of the elements a QAS might find in an "ideal" quality program.